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Oxidant Air Pollution in Remote Forested Areas of Southwestern Virginia. Oxidant Effect on Eastern White Pine

Virginia Polytechnic Inst and State Univ, Blacksburg

Prepared for

Corvallis Environmental Research Lab, Oreg

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**Corvallis
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Increases in oxidants were associated with winds from the north and northeast and stationary high pressure systems. Decreases in oxidants were associated with the passage of cold fronts from the northwest, warm fronts from the south, and winds from the west, southwest, south, and southeast. The National Ambient Air Quality Standard for photochemical oxidants of 8 pphm/1 hour/year was equaled or exceeded for 104, 78, and 39 hours at Sites I, II, and III, respectively. The highest mean hourly oxidant concentrations were monitored on July 3, 1975, the result of an air mass originating from the northeast urban areas.

A high degree of linear association was found between the severity index of needle injury of the sensitive class Site I field trees and cumulative levels of oxidants monitored during photosynthesis. Of four lines of grafted white pine trees planted at all three sites, the sensitive lines (W-4-S, W-1-S) were severely injured while the tolerant lines (PA-10-T, W-5-T) remained symptomless. Increases in injury to white pine were observed at all sites following the high levels of oxidants recorded on July

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SOUTHWESTERN VIRGINIA
Oxidant Effect on Eastern White Pine

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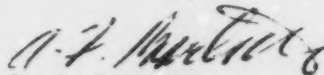
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FOREWORD

Effective regulatory and enforcement actions by the Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory (CERL).

The primary mission of the Corvallis Laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lake systems; and the development of predictive models on the movement of pollutants in the biosphere.

This report documents the common occurrence and associated terrestrial effects of oxidant air pollution in forested areas far removed from major sources.



A. F. Bartsch
Director, CERL

ABSTRACT

Total oxidants and associated oxidant injury to white pine were determined at three rural sites in Virginia: (1) Salt Pond Mountain, Giles County; (2) Rocky Knob Mountain, Floyd County; and, (3) Shenandoah Valley, Rockingham County, at 945 m, 945m, and 426 m elevation, respectively. Oxidants were monitored with Mast Meters (Model 724-2) from April 1975 to March 1976 at Site I, from May 1975 to March 1976 at Site II, and from May 1975 to October 1975 at Site III.

Increases in oxidants were associated with winds from the north and northeast and stationary high pressure systems. Decreases in oxidants were associated with the passage of cold fronts from the northwest, warm fronts from the south, and winds from the west, southwest, south, and southeast. The National Ambient Air Quality Standard for photochemical oxidants of 8 pphm/1 hour/year was equaled or exceeded for 104, 78, and 39 hours at Sites I, II, and III, respectively. The highest mean hourly oxidant concentrations were monitored on July 3, 1975, the result of an air mass originating from the northeast urban areas.

A high degree of linear association was found between the severity index of needle injury of the sensitive class Site I field trees and cumulative levels of oxidants monitored during photosynthesis. Of four lines of grafted white pine trees planted at all three sites, the sensitive lines (W-4-S, W-1-S) were severely injured while the tolerant lines (PA-10-T, W-5-T) remained symptomless. Increases in injury to white pine were observed at all sites following the high levels of oxidants recorded on July 3, 1975.

This report was submitted in fulfillment of EPA Contract No. CC6761010-J by the Department of Plant Pathology and Physiology, Virginia Polytechnic Institute and State University at Blacksburg, Virginia. The contract covered the period April 1975 to March 1976 and was completed July 15, 1976.

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ABBREVIATIONS AND SYMBOLS

FROP - frequency of oxidant peaks

MOPPAD - mean of days as percent of peak on any day

MNPKHR - mean hourly oxidant concentration in pphm.

 - wind direction and magnitude

● - passage of frontal systems

O - high pressure system

NAAQS - National Ambient Air Quality Standard

W-4-S - W-4 line, sensitive grafted tree

W-1-S - W-1 line, sensitive grafted tree

PA-10-T - PA-10 line, tolerant grafted tree

W-5-T - W-5 line, tolerant grafted tree

C - chlorotic

CS - chlorotic spot

CB - chlorotic band

CM - chlorotic mottle

NB - necrotic band

TB - tip burn

>S - increase in severity

M - meter

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SECTION I

INTRODUCTION

The population growth rate of the United States and the world today is placing enormous demands on the world's resources. To keep pace with the accelerated growth, exceptional increases in industrialization and urbanization have taken place in the more advanced areas of the world. The waste products of this greatly expanded growth have lead to far reaching and predominantly detrimental effects to the environment. Gaseous waste products emitted into the atmosphere as air pollutants have been, and will continue to be in the foreseeable future, a major problem.

The air pollution associated with our metropolitan areas is the result of increases in the emissions from all forms of transportation, manufacturing industries, and the generation of electrical power.

For the past 15 years the threat of air pollutants to natural plant communities in the rural areas of the country was limited due to the presumed buffering or dilution effect of distance from major urban centers or other pollution sources. It has now become evident that the distance between remote forested areas to the urban industrial areas decreases in significance as pollution increases. The emission intensities associated with metropolitan areas today are now resulting in injurious air pollutants in rural forested areas (34). Once a problem in cities only, air pollutants are now a condition of concern in rural areas as well.

Oxidant injury to large areas of forest vegetation was first identified in the San Bernardino mountains adjacent to the Los Angeles basin in 1962 (35). Since that time, decline and eventual mortality of forest trees has lead to dramatic changes in the forest ecosystem (33).

The timber and plant communities in the Appalachian Mountains and Blue Ridge Mountains of Virginia are important sources of timber, watersheds, and recreational areas. These areas are now being threatened by air pollutants emitted from the large almost continuous expanse of cities and industries on the East Coast of the United States.

Prior to initiating this study, oxidant injury and decline were determined on eastern white pine in the western mountains of the Shenandoah Valley; actual mortality of mature trees was observed (36).

The specific objectives of this study were to:

- 1) To determine the levels of oxidants that exist in the remote forested areas of the mountains of southwestern Virginia.
- 2) To associate ambient monitored levels of oxidants with increases in injury to eastern white pine (Pinus strobus L.).

SECTION II

SUMMARY

The purpose of this investigation was to determine the levels of oxidants that exist in the remote forested areas of southwestern Virginia and to associate such levels with oxidant injury to eastern white pine.

Three monitoring sites were located in southwestern Virginia. Site I was on Salt Pond Mountain at 945 m in elevation in Giles County; Site II was on Rocky Knob Mountain at 945 m in elevation in Floyd County; and Site III was located in the Shenandoah Valley at 426 m in elevation in Rockingham County, Virginia.

Oxidants were also briefly monitored at the Fruit Extension Research Station in Winchester, Virginia during the Winter months of 1976.

Increases in oxidant concentrations were associated with winds from the north and northeast and stationary high pressure systems, while decreases in oxidant concentrations were associated with the passage of cold fronts from the northwest, warm fronts from the south, and with high winds from the west, southwest, south, and southeast.

High mean hourly oxidant concentrations were monitored frequently in excess of the National Ambient Air Quality Standard of 8 pphm during the year. From April, 1975 to March, 1976, Sites I, II, and III recorded 104, 78, and 39 hours, respectively, equal to or exceeding this level.

The highest mean hourly oxidant concentrations were monitored on July 3, 1975. The high oxidant concentrations of July 3, 1975

were the result of transport from the urban complexes of the Northeastern United States into the mountainous areas of Southwestern Virginia.

During another period of high oxidant concentrations on February 29, 1976, the 2 southwest mountain sites recorded numerous hours above the National Ambient Air Quality Standard. The Winchester site verified these levels over the same time period.

A 2- and 3-fold increase in oxidant concentrations over those monitored 13 and 14 years ago by Dr. Charles Berry, of the U.S.D.A. Forest Service, was determined.

Twenty one eastern white pines within a planted 15-year-old stand were classified as sensitive, intermediate, and tolerant with 7 trees per class. Symptoms were rated at approximately 11 day intervals during the growing season by the following scale: 1) chlorotic spot, 2) chlorotic mottle, 3) chlorotic band, 4) chlorotic tip, 5) necrotic spot, 6) necrotic band, and 7) tip burn. The severity index of needle injury was the type of symptom multiplied by the percent injury.

At all three sites 24 potted, grafted white pines were planted. There were 4 lines of sensitivity, 2 sensitive (W-4-S, W-1-S) and 2 tolerant (PA-10-T, W-5-T). At each site, 6 trees of each line were planted.

A high degree of linear association was found between the sensitive Site I field trees and cumulative oxidants monitored during the hours of photosynthesis (7:00 a.m. to 8:00 p.m.). The injury to

these sensitive field trees was severe. It was expressed as tip necrosis. By mid-August 80% of the tissue on most of these sensitive trees was necrotic and the remaining tissue was mottled. The intermediate Site I field trees expressed chlorotic spots and in severe cases, chlorotic mottle. The tolerant Site I field trees remained essentially free of the named symptoms.

The 2 lines of sensitive grafted trees (W-4-S, W-1-S) were severely injured by oxidant while the tolerant grafts (PA-10-T, W-5-T) remained free of symptoms. The W-4-S grafts at Site II were initially the most severely injured due to the higher levels of oxidants being monitored at that site.

All of the intermediate Site I field trees (with the exception of tree 7), the sensitive Site I field trees, and the W-1-S sensitive grafts showed increases in injury from July 1 to July 10, 1975 as a result of the high levels of oxidants transported into the mountains of southwestern Virginia on July 2, and 3, 1975.

The results of this study indicate that high levels of oxidants are causing injury to oxidant sensitive and intermediate sensitive eastern white pine trees.

SECTION III

CONCLUSIONS

1. The rural oxidant concentrations in southwestern Virginia are influenced by the surrounding urban environments.
2. The National Ambient Air Quality Standard (NAAQS) of 8 pphm not to be exceeded more than one hour once per year was frequently exceeded at all three rural sites.
3. There were several days in which the NAAQS was exceeded at all sites over the same hours indicating the large geographical extent of oxidant air pollution over southwestern Virginia.
4. Transport of oxidant air pollution in excess of the NAAQS was determined to have taken place over several hundred miles during one period of this study.
5. A significant increase in oxidant concentrations was determined to have taken place in the mountainous areas of southwestern Virginia over levels monitored 13 and 14 years ago.
6. A high degree of linear association was determined between cumulative levels of oxidants monitored during the hours of photosynthesis and the severity index of the site I sensitive field trees.
7. Two lines of sensitive grafted trees were severely injured by oxidants while two lines of tolerant grafted trees remained symptomless.
8. Oxidant injury to eastern white pine is occurring in the mountainous areas of southwestern Virginia.

SECTION IV

RECOMMENDATIONS

1. Continue monitoring photo chemical oxidants in southwestern Virginia to determine increasing levels.
2. Continue to monitor meteorological conditions on the eastern half of the United States to determine extent of long distance transport.
3. Locate meteorological equipment at all sites to determine influence of microclimate on the oxidant concentrations.
4. Locate a valley monitor adjacent to a mountain top monitor to determine oxidant movement. A series of monitors may be necessary.
5. Continue monitoring symptom development on all classes of eastern white pine, field and grafted trees.
6. Expand plant studies to include Virginia pine then other conifer and hardwood species.
7. Determine extent and influence of the inversion area of southwestern Virginia on oxidant concentrations.
8. Use area averages of oxidant concentrations and quantitatively relate high pressure and oxidant concentrations.
9. Make further investigations of oxidant variability in mountainous terrain by use of computer analysis.
10. Analyze the potential self generation of oxidants induced by natural vs manmade HC sources.

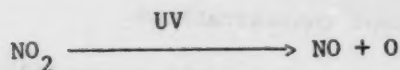
SECTION V

MAIN TEXT

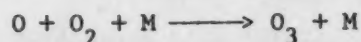
Reported Concentrations and Transport of Photochemical Oxidants

Oxidants are a major group of pollutants which include ozone (O_3), oxides of nitrogen (NO_x), and peroxyacetylnitrates (PANs). The most important source of photochemical oxidants in the lower atmosphere is the result of atmospheric reactions of hydrocarbons and oxides of nitrogen.

In an urban reaction system characteristic of a metropolitan area, the principle source of the hydrocarbons and oxides of nitrogen is from automobile exhausts (23). In the urban reaction system, oxidants (primarily O_3), are generated photochemically in the following fashion:

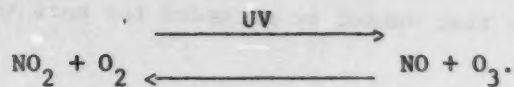


Active oxygen atoms react quickly with molecular oxygen to form ozone as follows:



M is any other molecule in the system which is needed to absorb the energy of the reaction.

Excess ozone formation, however, is not as simple because the nitric oxide and ozone react with each other to regenerate the reactants. The result is the set up of a steady state equilibrium in a very few minutes at which point the only continuing process is the absorption of sunlight and its conversion into heat.

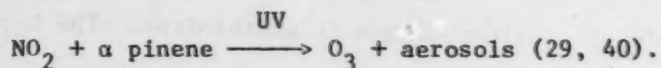


To unbalance the steady state condition in favor of formation of excess ozone, a reaction is needed to speed up the conversion of nitric oxide to nitrogen dioxide without consuming an equivalent amount of ozone. The oxidation of the hydrocarbon peroxy radicals yields an oxygen atom to nitric oxide forming nitrogen dioxide which further results in a formation of excess ozone (43).

As the ratio of hydrocarbon to oxides of nitrogen increases, the oxidant dosage increases (23), resulting in the typical diurnal pattern of oxidant generation associated with the urban reaction system.

Forest vegetation is the major source of hydrocarbons in a rural or natural reaction system (39). A major source of nitrogen dioxide in a natural environment results from nitric oxide formed by bacterial action in the reduction of nitrogen compounds under anaerobic conditions (41).

Synthesis of ozone in a rural environment has recently been shown to occur by the following reaction:



The national ambient air quality standard (NAAQS) for photochemical oxidants is 8 pphm or $160 \mu\text{g}/\text{M}^3$. This is the maximum

hourly average that cannot be exceeded for more than 1 hour once per year. (4)

In 1961 in a remote forested valley in Pocahontas County, West Virginia, Berry (7) monitored photochemical oxidants from June 9 to July 6. The highest hourly average concentration recorded was 6.5 pphm for 4 consecutive hours. From June 19 to July 10, 1962 on a forested mountaintop in North Carolina, the highest hourly average was 2.5 pphm for one hour.

Recently, high levels of ozone in excess of the NAAQS for photochemical oxidants have been reported (2, 3, 5, 10, 11, 34).

Monitoring ozone in rural Garrett County, Maryland, from August 29 to September 25, 1972, researchers found the NAAQS to be exceeded 11.26% of the time; one period lasted 26 consecutive hours (2). The mean for the period was 5.7 pphm. Similar high ozone concentrations were found in the rural Mount Storm area of West Virginia (3). Based on these findings and reports from other researchers, the following hypothesis was proposed (2). Ozone precursors are released into the troposphere at a location remote from the rural study area. Given appropriate meteorological conditions the precursors are transported to the study area. During transport and in the presence of sunlight, ozone is synthesized. The hypothesis further assumes that by sundown the precursors (which are also destructive agents) are consumed, leaving high residual ozone concentrations which are transported to the surface by mechanical turbulence.

Coffey and Stasulk (12) reported ozone concentrations in excess of the NAAQS to be common in the rural areas of New York State. In their study, urban ozone peak concentrations were interpreted primarily as the result of the high background levels of ozone and not local photochemical generation. Their purpose was to present an alternative to the local photochemical process as the cause of most urban ozone in the New York State area.

Miller et al. (34) reported evidence of transport of high levels of photochemical oxidant air pollution from population centers in the San Joaquin Valley to a higher elevation valley in the Sierra Nevada foothills. Oxidants were monitored by aircraft and ground stations. They further reported that the primary pollutants (NO_x and hydrocarbons) necessary for the early morning formation of ozone in Mineral King Valley (a rural site) were probably advected from the foothills or from Central Valley (an urban site). Miller, et al. further hypothesized that the more abundant ultraviolet light at the higher elevations may be a significant factor increasing the rate of ozone accumulation, particularly during the morning hours.

Cleveland and Kleiner (10), working in New Jersey and Pennsylvania, found that the ozone concentrations were higher when air was flowing from the Camden-Philadelphia urban complex, to rural monitoring sites 27 km to 49 km distant. They proposed that this phenomenon may have accounted for some of the ozone previously observed in the non-industrial, low-traffic density area of Ancora,

New Jersey. Concentrations of primary pollutants in Ancora are low, but average hourly concentration frequently exceeded the NAAQS. They concluded that photochemical air pollution in this area is a regional rather than a local phenomenon, and that ozone resulting from the urban complex is widespread and not confined to the complex itself. In 1976, Cleveland and Kleiner (11) reported that their data on emissions in the New York City metropolitan area are responsible for the high concentrations of ozone in southwestern Connecticut. For a large number of individual days during the sampling period, the movement of photochemical air pollution from one geographical region to another was quite evident. On July 2, 1974, photochemical air pollutants resulting from primary emissions in the New York City metropolitan area were transported by prevailing winds on a 300-kilometer northeast trajectory through Connecticut and as far as northeastern Massachusetts. As a result, southwestern Connecticut had the highest ozone concentrations in the region and there was a substantial increase in ozone concentrations in Massachusetts.

In the Summer of 1975 in the Ohio Valley, researchers found that the NAAQS for photochemical oxidants was exceeded approximately twice as frequently at the rural stations as at the urban stations (5). Periods were reported (at times, 5 days or more) when the near surface concentration of ozone equalled or exceeded the NAAQS over large geographical areas. Ozone precursors of anthropogenic origin were demonstrated in this air by the presence of acetylene in all hydrocarbon samples and the presence of high carbon monoxide concentrations.

Further, when the central region of a high pressure system moved into the region of interest, high concentrations of ozone were reported at all stations. No specific trajectory could be uniformly associated with the arrival of air containing either high or low concentrations of ozone at any of the rural sites.

Effects of Air Pollutants on Eastern White Pine; Ozone

Photochemical oxidant air pollution (primarily O_3) was first identified in 1967 as the agent responsible for the slow decline and death of ponderosa pine (Pinus ponderosa Laws.) trees in southern California (35). Work on identifying the source of the damage began in the mid-1950's; when it was described as "chlorotic decline" (37). Since that time, extensive mortality (8% to 10% from 1968 to 1972) of ponderosa pines has resulted in dramatic changes in the composition of the ponderosa pine-sugar pine-fir forest type on the San Bernardino National Forest (33).

In the Shenandoah Valley of Virginia in 1973, Morris (36) reported that 30% of the white pines in an area of Rockingham County, Virginia, exhibited visible injury and 5% were severely affected or completely brown as observed from an aerial survey. In 1971, 15 trees were tagged, and after 2 years of exposure 13 trees were shown to have declined. Of the 13 trees, 6 died after what appeared to be a result of three consecutive exposures. He estimated a 3% mortality of eastern white pine (Pinus strobus L.) in the affected area.

Since the early 1900's a disease of eastern white pine generally called "needle blight" characterized by stunting, chlorosis, and/or

tip necrosis of needles has been reported throughout the range of the species. The disease was first described in 1908 by Dana (15) and Spaulding in 1909 (42).

In 1961, Berry (6) described emergence tipburn, referred to above as white pine "needle blight." This disease complex has also been called white pine blight, and white pine needle dieback; each being characterized by the dying of the tips of the new elongating needles in June or July. In his study, Berry found that healthy scions remained healthy when grafted to diseased root stock and diseased scions remained diseased when grafted to healthy root stock supporting the hypothesis that the causal factor of the tipburn was an atmospheric agent.

Linzon (31) found similar results when he investigated the genetic character of the disease, showing that grafted partners retained their original identity. He concluded that the cellular make-up of needle-blighted trees which makes them susceptible to needle breakdown is an inherited trait.

Further investigation by Hepting and Berry (24) distinguished and reported three distinct needle maladies occurring on white pine. These were emergence tipburn, postemergence acute tipburn, and postemergence chronic tipburn. They proposed that emergence tipburn was the same as the "needle blight" disease of the past, mentioned earlier, the cause of which defied so many researchers. During the growing season, the distal parts of the needles become reddish-brown, then brown, and later grayish, after which the dead tips usually break off.

Only the current year's needles are affected. A given tree is generally quite uniformly affected, and its needles may be dead just a short way back from the tips, or for most of their length. The affected needles are not shed prematurely. There is a tendency for the same trees to show this symptom during "blight" years, indicating the genetic susceptibility, and for neighboring trees to remain consistently free from this symptom. The band of demarcation between the living and dead portion of the needle is very narrow, and usually a yellow-green band is present during certain years. Emergence tipburn may occur over large areas throughout the East, and in other years it is hard to find. Emergence tipburn may recur perennially, and dominant trees have been shown to decline and die as a result of injury.

Postemergence acute tipburn is a sudden browning of some or all of the foliage often involving the entire length of the needles. Postemergence acute tipburn may occur at any time of the year affecting both current and older needles. Needles may be shed in quantity shortly after the damage appears.

Postemergence chronic tipburn is particularly similar to emergence tipburn in many respects. Postemergence chronic tipburn includes the marked tree to tree variation from none to severe blighting and the often shortened and somewhat yellowish foliage. The marked reduction in shoot growth that accompanies severe blighting and the frequent involvement of needles of the current year. It differs, in that the needle browning may appear at any time of the year

rather than just during the growing season. Also, the needles usually show a gradual dieback from the tips with a gradient from brown at the tip to green at the base; some mottling of the green parts may also occur. As in the case of emergence tipburn the line of separation between blighted and unblighted tissue is sharp. When damage is severe, affected trees are consistently short and often off-color with brown tips. The shoot growth becomes progressively shorter.

Linzon (31) confirmed the findings of Berry and Hepting (24) by noting that emergence tipburn occurred on limited areas at the tips of needles and that with postemergence injury the lesion involved most of the needle length. He also showed that the semi-mature tissue was the most sensitive by noting where new lesions occurred during the growing season. Based on this and further work, Linzon later renamed the disease SNB (semi-mature needle blight) (32).

In Pocahontas County, W. Va. during 1961, Berry (8) observed that white pine emergence tipburn had occurred during a period of high atmospheric oxidant concentrations. Oxidant concentrations of 6.5 pphm were recorded. Potted sensitive white pine ramets were protected from emergence tipburn by placing them in a chamber supplied with filtered air by passing through activated carbon. Typical disease symptoms were produced on ramets in the greenhouse, using artificially produced oxidant at concentrations and exposure times similar to those recorded in the field. Thus, the hypothesis that an

oxidant, probably ozone, is a cause of emergence tipburn of white pine was strengthened.

Costonis and Sinclair (14) reported that ozone, administered at time-concentration combinations (3 pphm for 48 hours and 7 pphm for 4 hours) monitored in the atmosphere of a rural pine stand caused acute injury to current-season needles on field and potted trees. Acute symptoms of ozone injury on sensitive needles of the current season were exhibited as silver flecks caused by collapse of individual mesophyll cells beneath the stomatal surfaces of the needles. These coalesced to form yellow to pink spots, necrotic bands, and necrotic tips. Chronic symptoms were reported as chlorosis and premature casting of the older foliage and slow growth of trees. Costonis and Sinclair (14) found that acute symptoms may appear as early as 12-24 hours after acute exposure to ozone.

Linzon (30) described initial symptom development in a similar fashion. Lesion development began with faint pinkish spots on the stomata-bearing faces of needles in semi-mature tissue. These spots developed rapidly into orange-red bands which within a few days spread to the needle tips.

The term "chlorotic dwarf" was first used by Swingle (44) to describe a complex found in young plantations of eastern white pines. Chlorotic dwarf trees are characterized by having stunted shoots and tops, short mottled needles, and premature shedding of foliage (16). Previously Dochinger and Seliskar (19) had shown by grafting techniques that the condition of chlorotic dwarf is controlled by

inherited factors and is caused by an atmospheric agent acting on the foliage. Further work (20) showed that chlorotic dwarf trees recovered when they were kept in chambers from which incoming ambient air was carbon filtered.

Effects of Air Pollutants on Eastern White Pine; Other Oxidants

Ozone, oxides of nitrogen, other photochemical oxidants, and SO_2 have all been implicated in the chlorotic dwarf condition (16, 17, 20, 21).

Dochinger and Seliskar (20) found that the production of symptoms on sensitive ramets was related directly to ambient levels of single and multiple pollutants in white pine plantations. Laboratory studies showed that ozone and sulfur dioxide, independently or synergistically, promote early symptoms of needle mottling and premature defoliation in the chlorotic dwarf syndrome.

Costonis (13) demonstrated that certain strains of eastern white pine are extremely sensitive to low levels of SO_2 . No differences of diagnostic significance were noted between O_3 and SO_2 injury. The pattern of lesion development was similar and could easily be confused.

Houston (25) also reported that low levels of SO_2 could cause injury to sensitive white pines. Ozone exposures did not produce a consistent response among tolerant and sensitive classes, while injury caused by SO_2 and SO_2 plus O_3 correlated well with field observations of damage under ambient conditions. The most sensitive clone was injured by concentrations of SO_2 as low as 2.5 ± 1 ppm. The interaction

of SO_2 and O_3 at low concentrations was established as more serious than that caused by either pollutant alone at similar levels.

SECTION VI

MATERIALS AND METHODS

Locations of Monitoring Sites

Three rural monitoring sites were selected in southwestern Virginia. Site I was located on a southwest facing slope of Salt Pond Mountain at 945 m in elevation in Giles County, Virginia. This site is located on private land owned by Ruth and Miles Horton. Monitoring of total oxidants began at Site I on April 9, 1975 and continued to March 31, 1976. Site II was located on a north-facing aspect of Rocky Knob Mountain at 945 m in elevation in Floyd County, Virginia adjacent to the Blue Ridge Parkway; the land is owned by the U. S. Park Service. Site III was located in the northwestern section of the Shenandoah Valley in Rockingham County, Virginia. The monitoring site is 426 m in elevation at the foot of the Shenandoah mountains. This site is located on Rawley Springs Road in Dayton, Virginia on private land owned by Mr. E. R. Adcock. Monitoring began on May 1, 1975 at Sites II and III and ended at Site II on March 31, 1976 and at Site III on October 25, 1975.

During the winter months of 1976 total oxidants were monitored intermittantly in Winchester, Virginia; the results will be briefly mentioned.

Monitoring Equipment

Total oxidant concentrations were continuously monitored with Mast Meters (Model 724-2), Mast Development Corporation, Davenport,

Iowa, and Mast continuous chart line recorders (Model 725-3C2). Calibrations were run every 4 to 5 weeks in the Air Pollution Laboratory on campus. The potassium-iodine method of calibration was used. Equivalent concentrations of 1 ml of O_3 per ml were made by diluting a stock solution of .025 ml₂ with an absorbing solution of 1% KI. From these dilutions a standardized graph was drawn using a spectrophotometer and plotting percent transmittance against ozone concentration in pphm. A clean Mast Meter with a fresh solution of 2% buffered KI then monitored ozone of known concentration in a fumigation chamber. Air was pulled at the rate of .028 m³ from the chamber through 10 ml of the absorbing solution. By placing the absorbing solution in a spectrophotometer the percent transmittance was read and from the standardized graph, the exact ozone concentration was determined. The oxidant level being monitored by the Mast Meter was taken as a percent of the exact ozone concentration to determine the meter's efficiency. A new efficiency was determined for each Mast Meter before it was placed at a monitoring site.

Meters and recorders were located within standard U. S. Weather Bureau station structures. Air samples were taken at approximately 0.17 m above ground level through a 6.4 mm teflon tube that extended 0.03 m beyond the monitoring shelter.

Evaluation of Oxidant Charts

The charts produced by the Mast recorders at all three sites were dated and the average concentration in pphm over each hour was



read and recorded. The hourly average concentrations were then converted to ambient concentration levels according to the efficiency of the Mast Meter during the monitoring time. Data were subsequently fed into a Fortran program for computer analysis using a 370 IBM computer (Appendix Table 1).

Evaluation of Weather Data

Weather data were obtained from Daily Weather Maps, weekly series, published by the U. S. Weather Bureau in Washington, D. C. (45).

The passage of frontal systems, cold fronts from the northwest and warm fronts from the south and the presence of high pressure systems were noted when they directly affected the weather conditions over Virginia.

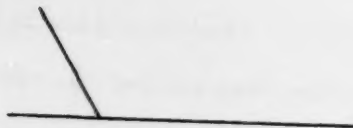
The wind direction and wind magnitude data were taken from the Roanoke U. S. Weather Bureau station located at Woodrum Field Airport in Roanoke, Virginia. Wind direction and magnitude were recorded on days reported by the Roanoke station and during times in which the oxidant concentrations were increasing or decreasing (Figure 1).

Evaluation of Computer Analysis

The computer analysis was accomplished by means of a Fortran program run on a 370 IBM computer. In this program, various tables were printed yielding statistics such as, frequency of oxidant peaks (FROP); mean of days as percent of peak on any day (MDPPAD) in percent; the mean hourly oxidant concentration (MNPKHR) in pphm; total



A.



B.

Figure 1. Wind direction and magnitude arrows; A indicates wind is from the west at a higher magnitude than B.

cumulative oxidant; total cumulative oxidant during photosynthesis; and total cumulative oxidant during respiration.

The frequency of oxidant peaks (FROP) was considered to be the number of times the mean oxidant concentration peaked at a given hour during a given month. All mean oxidant concentrations used in the analysis were those means of individual hours over a given duration of analysis, i.e., all the 1:00 a.m.'s, 2:00 a.m.'s, etc.

The mean of days as percent of peak on any day (MDPPAD) was found by first finding the highest hourly oxidant concentration reported over a given month's data and then taking the hourly means as a percent of this maximum. The MDPPAD effectively assigns each hour a percent that was relative to all other hours and graphically presented a picture of the pattern of oxidant concentration.

The cumulative oxidant during photosynthesis was a summation of mean hourly oxidant concentration that occurred during the hours of photosynthesis over all days during the month. Photosynthesis was defined in the analysis as taking place from 7:00 a.m. until 9:00 p.m. The cumulative oxidant during respiration was a summation of the mean hourly oxidant concentration that occurred from the hours of 9:00 p.m. to 7:00 a.m., over all days in a given month.

White Pine Studies; Field Trees

At Site I (Salt Pond Mountain) 21 white pine trees within a planted 15-year-old stand were rated into one of three symptom expression classes (sensitive, intermediate, tolerant) with seven trees per class. Sensitive trees were characterized by stunted tree growth and

short needles with tip burn and chlorotic mottle symptoms; only the current year needles were present. Intermediate trees had longer needles with chlorotic spots and mottling symptoms; only current year needles were present. Tolerant trees had long deep green needles that were symptomless; 2-year-old needles were present.

After candle elongation and fascicle emergence in late May, one branch was randomly selected on each tree. On each branch the terminal and a lateral shoot were selected and 12 fascicles were marked with four colors of oil color paints on the bottom, middle, and top of each candle in the same sequence. All needles on all fascicles were rated for seven symptom types at approximately 11-day intervals during the growing season. Symptom expression was rated according to the following scale: 1) chlorotic spot; 2) chlorotic mottle; 3) chlorotic band; 4) chlorotic tip; 5) necrotic spot; 6) necrotic band; 7) tip burn. The severity index of needle injury was computed by multiplying the number of the symptom by the percent injury. The level of injury occurring on all needles in all fascicles on both lateral and terminal were summed to determine the total severity index of the tree on the rating day.

White Pine Studies; Field Tree, Statistical Analysis

To investigate the degree of linear relationship between the severity index of needle injury of the sensitive (chlorotic dwarf) trees and cumulative oxidant concentrations during photosynthesis the simple correlation coefficient r , an estimation for the correlation coefficient was computed. A linear regression analysis was also

chosen to establish a statistical model from which predictions of increased injury from increased concentrations of oxidants would be possible. The regression equation was: $Y = a + b x$, where Y is the mean of severity index of needle injury for a fixed level of cumulative oxidant during photosynthesis; x, is equal to cumulative oxidant during photosynthesis, and the coefficients a and b are the intercept and slope, respectively. The intercept is the value of the mean of Y where x is equal to zero.

White Pine Studies; Grafted Trees

Cuttings from eastern white pine trees of four lines of sensitivity, two sensitive (W-4-S, W-1-S) and two tolerant (PA-10-T, W-5-T) were obtained in March 1975 from Dr. Charles Berry with the U.S.D.A. Forest Service, in Ashville, North Carolina. Dr. Berry is now with the U.S.D.A. Forest Service in Athens, Georgia. These lines were field tested by Dr. Berry at Ashville to determine their relative sensitivities.

Cuttings were taken from the terminal portions of trees, placed into plastic bags and refrigerated for transport back to the V.P.I. & S.U. Campus. The cuttings were grafted during March 1975 to 2-0 Eastern white pine seedling stock grown in pots containing a uniform soil mix of two part Weblite, two parts Vermiculite, and one part sphagnum peat moss. Grafts were placed into a mist chamber until the candles began to elongate approximately 6 weeks later. The grafts were then allowed a hardening off period of 2 weeks in the charcoal filtered greenhouse.

At each monitoring site during the last week of May 1975, 24 grafted trees, six of each line were planted in a randomized block design adjacent to each monitor. The grafts remained in the plastic pots but the sides were cut at one inch interval all around the pots and the bottoms removed to allow the roots to obtain adequate soil moisture.

The grafts were rated at approximately 2 week intervals throughout the growing season. Each time the grafts were rated the type of symptom and the percent injury over all needles was recorded.

SECTION VII

RESULTS

Monitored Oxidant Concentrations and Meteorological Data

Figures 2 and 3 represent the mean hourly oxidant concentrations based on 24, one-hour averages over all days monitored at all sites. In addition these figures also contain the pertinent meteorological information; the influence of wind direction and magnitude; the influence of frontal systems and; the influence of high pressure systems.

Generally, the oxidant concentration reached high mean monthly levels in the summer months, then decreased to minimum levels in the winter months of December and January. Concentrations then increased again to the highest monthly mean concentrations of the monitored year in February and March 1976. The actual mean monthly oxidant concentrations based on number of days monitored at each site throughout the year are presented in Tables 1 and 2.

The highest mean hourly oxidant concentrations were recorded on July 3, 1975, at Site II, Figure 2.

Table 3 represents the number of hours and the percent of total hours throughout the year of each level of oxidant concentration recorded at Site I. Table 4 represents the same information for Site II, and Table 5 for Site III.

The highest mean hourly oxidant concentrations of the monitored year were recorded during a period in July 1975 and at the end of February and beginning of March 1976.

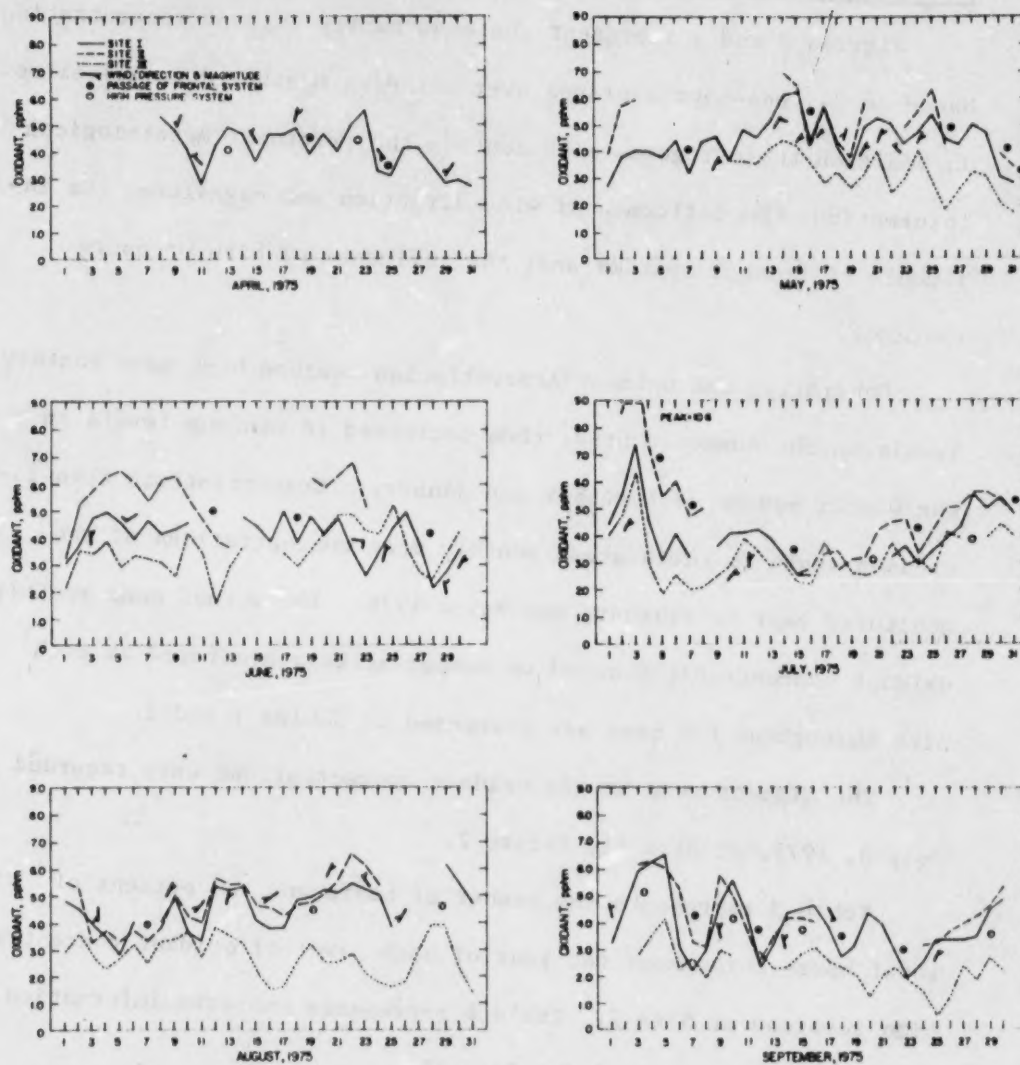


Figure 2. Mean hourly oxidant concentration in pphm from April to September 1975, based on 24, one hour averages at Sites I, II, and III.

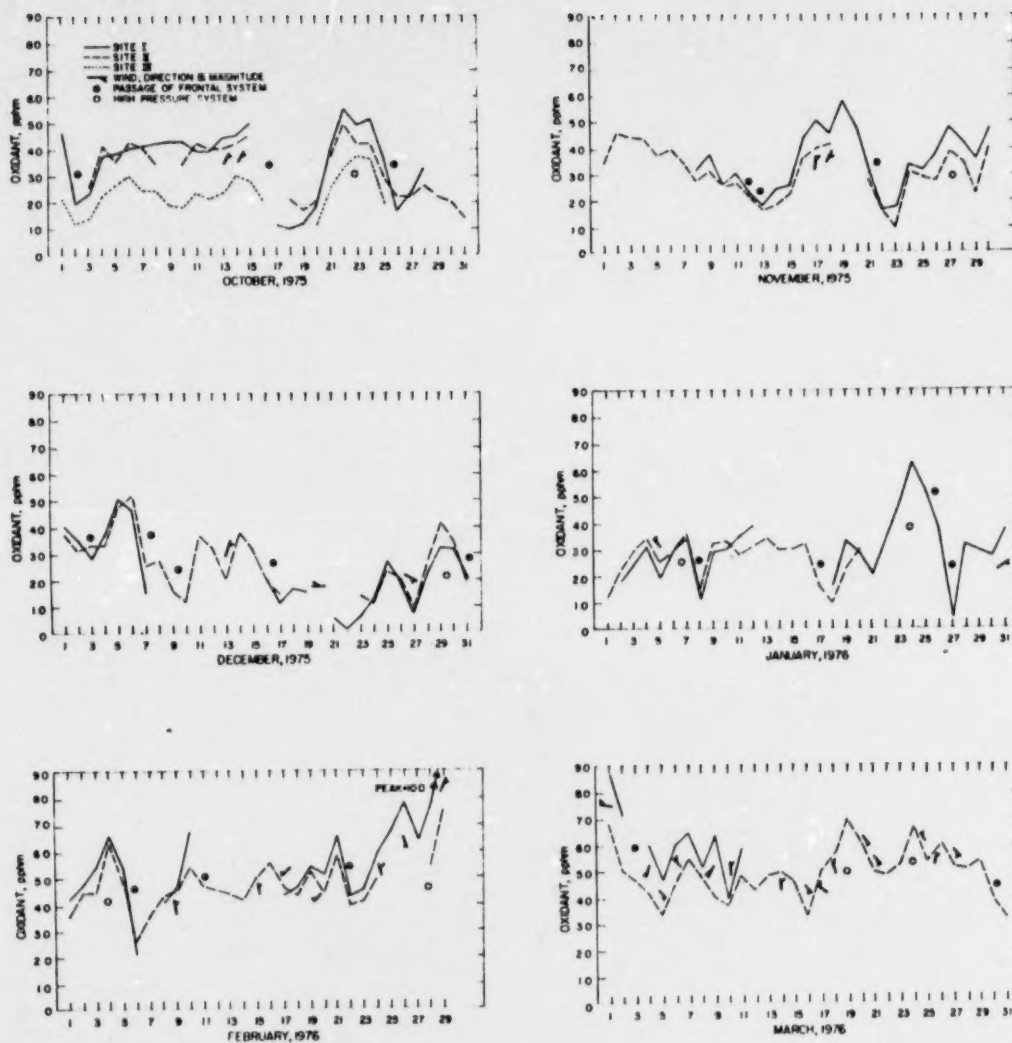


Figure 3. Mean hourly oxidant concentration in pphm from October 1975 to March 1976, based on 24, one hour averages at Sites I, II, and (for October only at Site III).

TABLE 1. MONTHLY MEAN OXIDANT CONCENTRATION IN PPHM AT SITES I, II, AND III FROM APRIL 1975 TO SEPTEMBER 1975 BASED ON NUMBER OF DAYS MONITORED.

Site	April		May		June		July		August		September	
	a	b	a	b	a	b	a	b	a	b	a	b
I	4.13	23	4.41	31	4.02	26	4.10	25	4.52	27	3.83	30
II	--	--	4.88	17	5.36	15	4.90	24	4.69	24	4.16	20
III	--	--	3.20	23	3.49	29	3.13	31	2.62	31	2.28	27

a Mean oxidant concentration.

b Number of days monitored.

- No data taken.

TABLE 2. MONTHLY MEAN OXIDANT CONCENTRATION IN PPHM AT SITES I, II, AND III FROM OCTOBER 1975 TO MARCH 1976 BASED ON NUMBER OF DAYS MONITORED.

Site	October		November		December		January		February		March	
	a	b	a	b	a	b	a	b	a	b	a	b
I	3.45	26	3.45	24	2.24	22	2.94	25	5.59	22	5.99	10
II	3.11	26	3.03	28	2.68	26	2.65	20	4.69	26	4.88	31
III	2.35	21	--	--	--	--	--	--	--	--	--	--

a Mean oxidant concentration.

b Number of days monitored.

- No data taken.

TABLE 3. NUMBER OF HOURS AND PERCENT TOTAL HOURS RECORDED AT SITE 1 AT EACH LEVEL OF OXIDANT CONCENTRATION.

Oxidant Concentration	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Number of hours:												
0.0 - .99	4	0	2	0	1	61	3	12	140	58	10	0
1.0 - 1.99	12	7	28	13	12	82	50	77	130	86	5	1
2.0 - 2.99	75	85	70	97	56	61	152	120	123	140	25	5
3.0 - 3.99	151	151	163	188	138	120	172	145	72	186	44	16
4.0 - 4.99	169	268	263	160	167	190	197	156	66	75	129	30
5.0 - 5.99	120	166	84	88	194	102	88	63	21	30	109	55
6.0 - 6.99	21	58	29	29	73	8	46	3	0	20	78	75
7.0 - 7.99	0	9	6	19	7	0	7	0	0	5	35	37
8.0 - 8.99	0	0	3	4	0	0	5	0	0	0	36	7
9.0 - 9.99	0	0	0	2	0	0	0	0	0	0	19	12
10.0 - 10.99	0	0	0	0	0	0	0	0	0	0	14	2
11.0 - 11.99	0	0	0	0	0	0	0	0	0	0	0	0
12.0 - 12.99	0	0	0	0	0	0	0	0	0	0	0	0
Percent of total hours:												
0.0 - .99	.7	.9	.3	.2	.2	9.8	.4	2.1	25.4	9.7	2.0	.4
1.0 - 1.99	2.2	11.4	4.3	2.2	1.9	13.1	6.9	13.4	23.6	14.3	1.0	
2.0 - 2.99	13.6	20.3	10.8	16.2	8.6	9.8	21.1	20.8	22.3	23.3	5.0	2.1
3.0 - 3.99	27.4	36.0	25.2	31.3	21.3	19.2	23.9	25.2	13.0	31.0	8.7	6.7
4.0 - 4.99	30.6	22.3	40.6	26.7	25.8	30.4	27.4	27.1	12.0	12.5	25.6	12.5
5.0 - 5.99	21.7	7.8	13.0	14.7	29.9	16.3	12.2	10.9	3.8	5.0	21.6	22.9
6.0 - 6.99	3.8	1.2	4.5	4.8	11.3	1.3	6.4	.5	0	3.3	15.5	36.3
7.0 - 7.99	0	0	.9	3.2	1.1	0	1.0	0	0	.8	6.9	15.4
8.0 - 8.99	0	0	.5	.7	0	0	.7	0	0	0	7.1	2.9
9.0 - 9.99	0	0	0	.3	0	0	0	0	0	0	3.8	5.0
10.0 - 10.99	0	0	0	0	0	0	0	0	0	0	2.8	.8
11.0 - 11.99	0	0	0	0	0	0	0	0	0	0	0	0
12.0 - 12.99	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 4. NUMBER OF HOURS AND PERCENT TOTAL HOURS RECORDED AT SITE II AT EACH LEVEL OF OXIDANT CONCENTRATION.

Oxidant Concentration	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Number of hours:												
0.0 - .99	--	10	0	0	0	18	13	40	58	41	7	8
1.0 - 1.99	--	0	8	14	0	80	11	114	135	94	5	39
2.0 - 2.99	--	23	12	68	31	146	90	145	149	118	21	112
3.0 - 3.99	--	81	36	103	119	168	113	179	141	203	119	200
4.0 - 4.99	--	95	92	142	178	176	92	184	82	24	227	250
5.0 - 5.99	--	84	79	135	175	36	82	10	33	0	177	95
6.0 - 6.99	--	94	109	59	58	0	63	0	2	0	52	32
7.0 - 7.99	--	15	16	12	13	0	13	0	0	0	32	8
8.0 - 8.99	--	5	8	4	1	0	3	0	0	0	8	0
9.0 - 9.99	--	1	0	14	0	0	0	0	0	0	0	0
10.0 - 10.99	--	0	0	16	1	0	0	0	0	0	0	0
11.0 - 11.99	--	0	0	8	0	0	0	0	0	0	0	0
12.0 - 12.99	--	0	0	1	0	0	0	0	0	0	0	0
Percent of total hours:												
0.0 - .99	--	2.5	0	0	0	2.9	2.7	6.0	9.7	8.5	1.1	0
1.0 - 1.99	--	0	2.2	2.4	0	12.8	2.3	17.0	22.5	19.6	.8	1.1
2.0 - 2.99	--	56.6	3.3	11.8	5.4	23.4	18.8	21.6	24.8	24.6	3.2	5.2
3.0 - 3.99	--	19.9	10.0	17.9	.7	26.9	23.5	26.6	23.5	42.3	18.4	15.1
4.0 - 4.99	--	23.3	25.6	24.7	30.9	28.2	19.2	27.4	13.7	5.0	35.0	26.9
5.0 - 5.99	--	20.6	21.9	23.4	30.4	5.8	17.1	1.5	5.5	0	27.3	33.6
6.0 - 6.99	--	23.0	30.3	10.2	10.1	0	13.1	0	.3	0	8.0	12.8
7.0 - 7.99	--	3.7	4.4	2.1	2.3	0	2.7	0	0	0	4.9	4.3
8.0 - 8.99	--	1.2	2.2	.7	.2	0	.6	0	0	0	1.2	1.1
9.0 - 9.99	--	.2	0	2.4	0	0	0	0	0	0	0	0
10.0 - 10.99	--	0	0	2.8	.2	0	0	0	0	0	0	0
11.0 - 11.99	--	0	0	1.4	0	0	0	0	0	0	0	0
12.0 - 12.99	--	0	0	.2	0	0	0	0	0	0	0	0

- No data taken.

TABLE 5. NUMBER OF HOURS AND PERCENT TOTAL HOURS RECORDED AT SITE III AT EACH LEVEL OF OXIDANT CONCENTRATION.

Oxidant Concentration	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb. ^a	Mar.
Number of hours:												
0.0 - .99	--	90	65	155	156	86	156	--	--	--	44	136
1.0 - 1.99	--	112	118	113	154	180	167	--	--	--	20	50
2.0 - 2.99	--	88	123	113	126	116	116	--	--	--	29	65
3.0 - 3.99	--	68	89	69	98	55	90	--	--	--	27	62
4.0 - 4.99	--	53	112	80	90	46	64	--	--	--	37	41
5.0 - 5.99	--	57	91	74	68	25	42	--	--	--	22	24
6.0 - 6.99	--	58	50	59	25	13	8	--	--	--	21	12
7.0 - 7.99	--	21	17	36	21	7	5	--	--	--	8	7
8.0 - 8.99	--	5	7	15	6	0	0	--	--	--	4	7
9.0 - 9.99	--	0	0	5	0	0	0	--	--	--	3	1
10.0 - 10.99	--	0	0	1	0	0	0	--	--	--	1	3
11.0 - 11.99	--	0	0	0	0	0	0	--	--	--	0	0
12.0 - 12.99	--	0	0	0	0	0	0	--	--	--	0	0
Percent of total hours:												
0.0 - .99	--	16.3	9.7	21.5	21.0	16.3	24.1	--	--	--	20.4	33.3
1.0 - 1.99	--	20.3	17.6	15.7	20.7	34.1	25.8	--	--	--	9.3	12.3
2.0 - 2.99	--	15.9	18.3	15.7	16.9	22.0	17.9	--	--	--	13.4	15.9
3.0 - 3.99	--	12.3	13.2	9.6	13.2	10.4	13.9	--	--	--	12.5	15.2
4.0 - 4.99	--	9.6	16.7	11.1	12.1	8.7	9.9	--	--	--	17.1	10.9
5.0 - 5.99	--	10.3	13.5	10.3	9.1	4.7	6.5	--	--	--	10.2	5.9
6.0 - 6.99	--	10.5	7.4	8.2	3.4	2.5	1.2	--	--	--	1.7	3.9
7.0 - 7.99	--	3.8	2.5	5.0	2.8	1.3	.8	--	--	--	3.7	1.7
8.0 - 8.99	--	.9	1.0	2.1	.8	0	0	--	--	--	1.9	1.7
9.0 - 9.99	--	0	0	.7	0	0	0	--	--	--	1.4	.2
10.0 - 10.99	--	0	0	.1	0	0	0	--	--	--	.5	.7
11.0 - 11.99	--	0	0	0	0	0	0	--	--	--	0	0
12.0 - 12.99	--	0	0	0	0	0	0	--	--	--	0	0

-- No data taken.

^a Data presented from Winchester, Virginia in February and March 1976.

On July 3, 1975, all three sites recorded concentrations above the National Ambient Air Quality Standard (NAAQS). Site I recorded 4 hours, Site III recorded 9 hours and Site II recorded 43 consecutive hours beginning at 1:00 p.m. on July 2, and ending at 5:00 a.m. on July 5. During the month of July, Site II recorded concentrations at or above the NAAQS over 7.5% of the total hours monitored (Table 4).

On February 29, 1976 during another period of high oxidant concentrations both mountain Sites I and II recorded hours above the NAAQS. Site II recorded 4 hours and Site I recorded 59 consecutive hours beginning at 12:00 a.m. on February 28 and ending 9:00 p.m. on March 1, 1976. This period of high oxidant concentrations resulted in 13.7 percent and 8.7 percent of the total hours monitored above the NAAQS for February and March 1976, respectively, at Site I (Table 3).

During the period of April 1975 to March 1976 Sites I, II, and III recorded 104, 78, and 39 hours, respectively, equal to or exceeding the NAAQS (Tables 3, 4, and 5).

The results from the meteorological data and the mean hourly oxidant concentrations (Figures 2 and 3) showed that increases in oxidant concentrations were associated with winds from the north and northeast and stationary high pressure systems. While decreases in oxidant concentrations were associated with passage of a frontal system, cold fronts from the northwest or warm fronts from the south, and with high winds from the northwest, southwest, south and southeast.

Generally, on days in which the Roanoke weather station reported winds from the northeast, all three sites would have daily mean peak concentrations on the same day, particularly evident July 3, 1975. On other days the Shenandoah Valley Site III did not peak on the same day, May 24, 1975. The influence from high pressure systems accounted for several periods of high oxidant concentrations during most months of the study.

The high oxidant concentrations of July 3, 1975 were the result of transport from the urban complexes of the Northeastern United States into the mountainous areas of Southwestern Virginia. On June 30 and July 1 a low pressure system (Hurricane Amy) became temporarily stationed off the Atlantic Coast adjacent to New York. A high pressure system had moved down from Canada becoming stationary over the Lake States (Figure 4a.). The air circulation around a low pressure system is counterclockwise and clockwise around a high pressure system. On July 2 this pattern remained the same, forcing air from the northeast down into Virginia (Figure 4b.). By July 3 the low pressure system had dissipated and a high pressure system had moved in over Virginia (Figure 4c.).

On July 3, under the influence of the high pressure system, the highest concentrations of oxidants were recorded. The weather conditions under a high pressure system are characterized as having disorganized wind flow, no movement of air into or out of a given geographical region, and clear to partly cloudy skies. These are optimum conditions for further generation of oxidants photochemically.

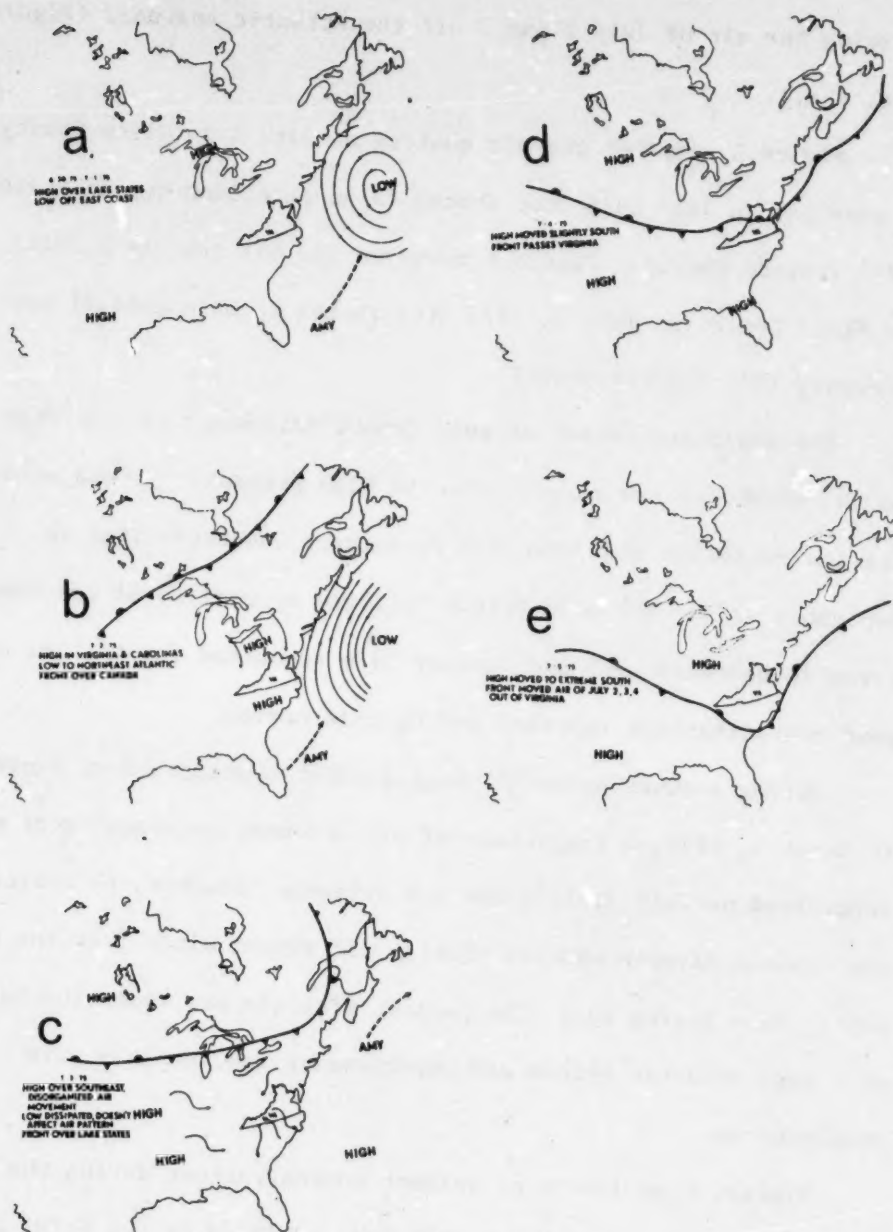


Figure 4. Weather patterns from June 30 to July 5, 1975 (45).

On July 4, a cold front originating over Canada passed over Virginia, forcing the air of July 2 and 3 off the Atlantic seaboard (Figure 4 d. & e.).

Figure 5 compares the air quality at Site I in Giles County on a poor day in July 1975 (top photo) to an excellent day in November 1975 (bottom photo). Figure 6 compares the air quality at Site II in Floyd County on July 3, 1975 (top photo) to an excellent day in December 1975 (bottom photo).

The rapid succession of cold fronts followed by winds from the north, northwest and the presence of high pressure systems accounted for the increases and decreases in oxidant concentrations in September 1975. The cold fronts followed by periods of low temperatures in December 1975 and January 1976 accounted for the low oxidant concentrations reported during this period.

During another period of high oxidant concentrations February 28 to March 1, 1976, a trajectory of air movement as specific as was determined on July 3, 1975 was not evident. However, on February 29 the Roanoke Airport weather station did report winds from the northeast. Also during this time period, Virginia was under the influence of a high pressure system and experiencing unseasonably warm temperatures.

Similar high levels of oxidant concentrations during the same period of February and March 1976 were verified by the brief monitoring done in Winchester, Virginia.

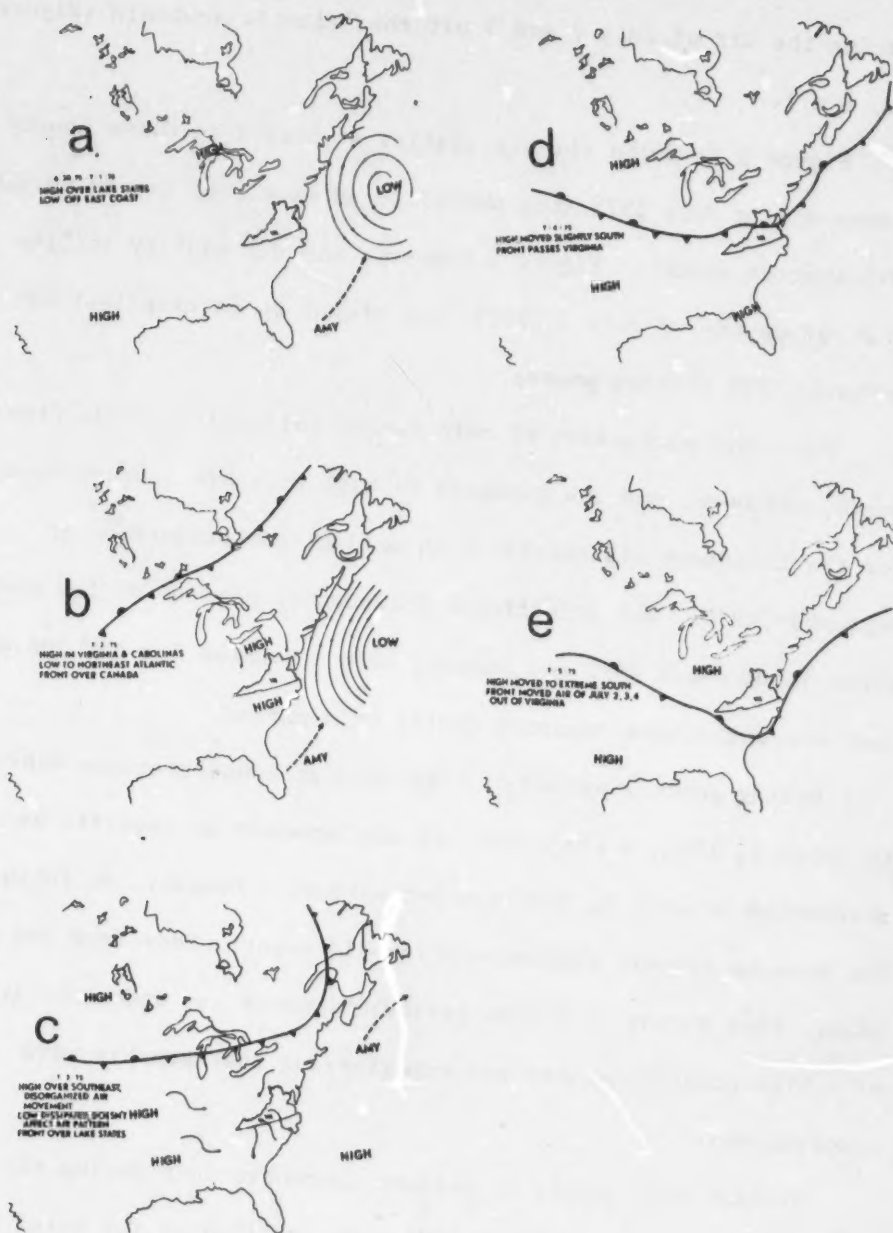


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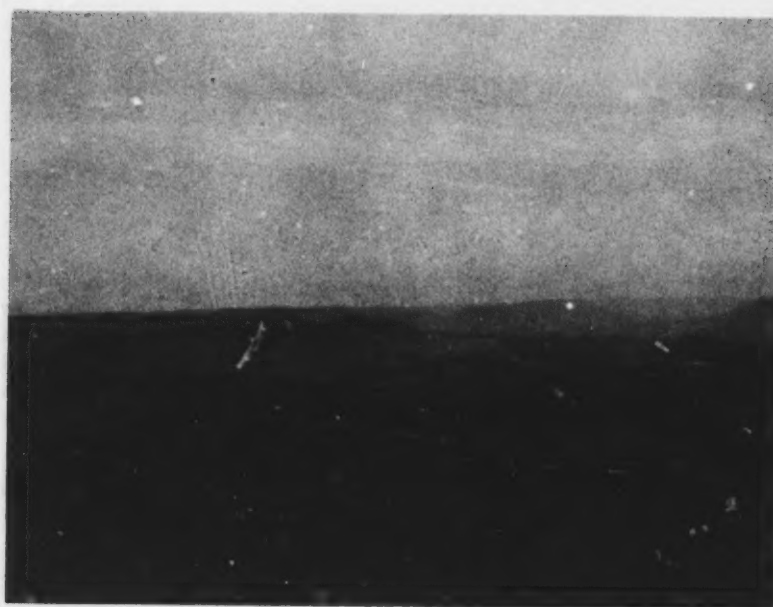


Figure 5. The air quality at Site I on a poor day in July 1975 (top) and on an excellent day in November 1975 (bottom).



Figure 6. The air quality at Site II on July 3, 1975 (top) and on an excellent day in December 1975 (bottom).

Comparison of Oxidant Concentration From 1961 and 1962 to Those
Determined in 1975

In 1961 and 1962, Dr. Charles Berry monitored oxidant concentration using Mast Meters and Mast Recorders at two rural locations (7). His data were selected as a comparison to the present study due to the significance of the mean hourly oxidant concentrations found in similar remote forested areas 13 and 14 years ago.

A comparison of the mean hourly oxidant concentration at Sites I and II from June 19 to July 10, 1975 to the mean hourly oxidant concentration from June 19 to July 10, 1961 on a mountain top in North Carolina is presented in Figure 7. This represents a 2-fold and 3-fold increase in the oxidant concentration at Sites I and II, respectively, over the levels monitored by Dr. Berry in 1962. The mean hourly oxidant concentration at Site III in the Shenandoah Valley from June 9 to July 6, 1975 was also compared to the mean hourly oxidant concentration from June 9 to July 6, 1961 in a valley site in Pocahontas County, West Virginia (Figure 8). This demonstrates an increase in the mean hourly oxidant concentration of approximately 2 pphm occurred during the afternoon hours.

Oxidant Concentrations in Mountainous Terrain

The results from the computer analysis; the frequency of oxidant peaks (FROP); the mean of days as percent of peak on any day (MDPPAD); and the mean hourly oxidant concentration (MNPKHR), described earlier, are presented in Tables 6 through 17.

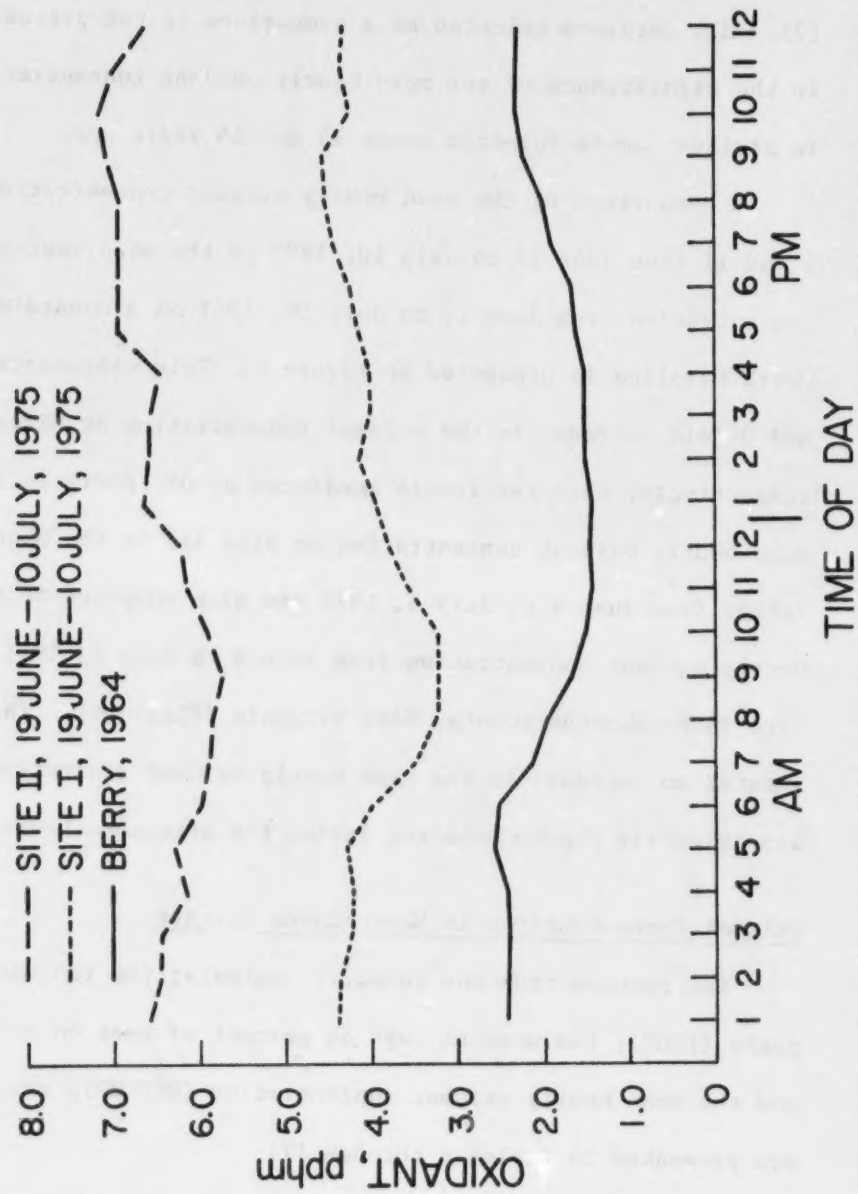


Figure 7. Mean hourly oxidant concentration in pphm from June 19 to July 10, 1975 at Site I and Site II compared to June 19 to July 10, 1961 on a mountain top in North Carolina, Berry 1964.

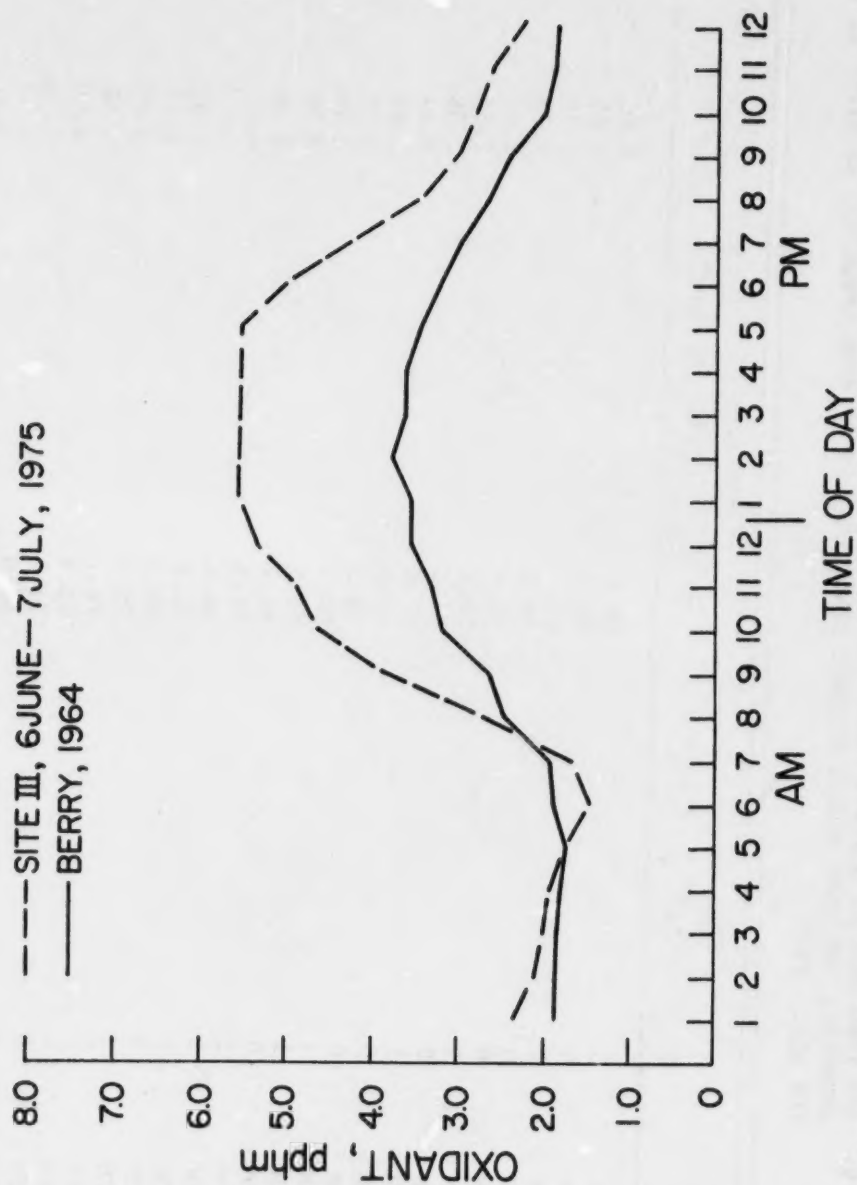


Figure 8. Mean hourly oxidant concentration in pphm from June 9 to July 7, 1975 at Site III compared to June 9 to July 7, 1962 in a valley in West Virginia, Berry, 1964.

TABLE 6. THE FREQUENCY OF OXIDANT PEAKS (FROP); THE MEAN OF LAYS AS PERCENT OF PEAK ON ANY DAY (MDPPAD); THE MEAN HOURLY OXIDANT CONCENTRATION IN PPHM (MNPKHR); AT SITES I, II, AND III FOR APRIL 1975.

HOURS	FROP			MDP PAD			MNPKHR		
	I	II ^a	III ^a	I	II ^a	III ^a	I	II ^a	III ^a
1 AM	5			66.4			4.16		
2 AM	0			64.3			4.03		
3 AM	1			62.9			3.94		
4 AM	0			59.5			3.73		
5 AM	0			58.7			3.68		
6 AM	1			58.2			3.65		
7 AM	0			57.2			3.58		
8 AM	1			57.8			3.62		
9 AM	0			58.7			3.68		
10 AM	0			59.8			3.75		
11 AM	1			60.5			3.79		
12 AM	1			63.5			3.98		
1 PM	0			66.4			4.16		
2 PM	1			71.3			4.47		
3 PM	1			74.4			4.67		
4 PM	2			75.3			4.72		
5 PM	3			75.5			4.74		
6 PM	2			75.3			4.72		
7 PM	1			74.7			4.68		
8 PM	0			73.3			4.60		
9 PM	0			71.5			4.48		
10 PM	2			68.0			4.26		
11 PM	1			66.4			4.16		
12 PM	0			65.5			4.11		

^a No data taken at Site II and III.

TABLE 7. THE FREQUENCY OF OXIDANT PEAKS (FROP); THE MEAN OF DAYS AS PERCENT OF PEAK ON ANY DAY (MDPPAD); THE MEAN HOURLY OXIDANT CONCENTRATION IN PPHM (MNPKHR); AT SITES I, II, AND III FOR MAY 1975.

HOURS	FROP			MDP PAD			MNPKHR		
	I	II	III	I	II	III	I	II	III
1 AM	3	3	0	56.7	57.0	18.7	4.46	5.18	1.59
2 AM	1	1	0	55.8	55.6	16.2	4.39	5.04	1.38
3 AM	1	0	0	55.7	54.6	15.4	4.39	4.96	1.32
4 AM	0	0	0	54.6	52.0	14.3	4.30	4.72	1.22
5 AM	1	0	0	54.7	51.1	13.2	4.31	4.64	1.13
6 AM	0	0	0	54.2	50.9	11.9	4.26	4.62	1.01
7 AM	0	0	0	53.1	48.8	13.3	4.18	4.43	1.14
8 AM	1	0	0	52.8	49.1	26.2	4.16	4.46	2.24
9 AM	1	1	0	48.4	51.3	40.7	3.81	4.66	3.47
10 AM	1	0	0	48.0	54.0	51.5	3.78	4.90	4.39
11 AM	1	1	1	51.9	56.3	59.7	4.08	5.11	5.10
12 AM	1	1	6	54.9	55.8	64.3	4.32	5.07	5.49
1 PM	1	1	2	56.9	54.6	67.1	4.48	4.96	5.73
2 PM	0	1	4	57.8	54.9	67.5	4.55	4.99	5.76
3 PM	5	0	7	59.7	52.0	68.3	4.70	4.72	5.83
4 PM	1	1	1	59.5	52.2	63.0	4.68	4.74	5.37
5 PM	1	0	2	59.9	53.4	64.4	4.71	4.85	5.49
6 PM	2	2	0	60.2	55.2	55.6	4.74	5.01	4.74
7 PM	1	0	0	59.5	56.2	45.4	4.68	5.10	3.87
8 PM	1	1	0	59.6	57.8	34.2	4.69	5.25	2.92
9 PM	2	2	0	58.7	55.9	27.8	4.62	5.08	2.37
10 PM	2	1	0	59.2	56.0	22.9	4.66	5.09	1.95
11 PM	1	1	0	57.7	54.0	20.8	4.54	4.90	1.77
12 PM	3	0	0	58.7	54.3	19.4	4.62	4.93	1.65

TABLE 8. THE FREQUENCY OF OXIDANT PEAKS (FROP); THE MEAN OF LAYS AS PERCENT OF PEAK ON ANY DAY (MDPPAD); THE MEAN HOURLY OXIDANT CONCENTRATION IN PPHM (MNPCHR); AT SITES I, II, AND III FOR JUNE 1975

HOURS	FROP			MDP PAD			MNPCHR		
	I	II	III	I	II	III	I	II	III
1 AM	5	2	0	52.5	64.6	24.8	4.34	5.57	2.08
2 AM	3	0	0	51.7	64.6	22.3	4.27	5.57	1.87
3 AM	0	1	0	50.8	62.9	21.4	4.21	5.42	1.80
4 AM	0	0	0	50.6	60.5	20.5	4.18	5.21	1.72
5 AM	0	0	1	49.6	58.3	18.7	4.10	5.03	1.57
6 AM	0	0	0	47.8	55.3	16.6	3.95	4.77	1.39
7 AM	0	0	0	44.0	52.8	17.8	3.64	4.55	1.49
8 AM	0	0	0	40.5	53.5	29.3	3.35	4.62	2.46
9 AM	0	0	0	41.3	53.3	43.9	3.41	4.60	3.68
10 AM	0	0	3	43.6	54.8	51.5	3.60	4.73	4.32
11 AM	0	0	2	47.1	55.6	55.6	3.89	4.79	4.67
12 AM	0	1	3	47.9	56.9	60.9	3.96	4.90	5.11
1 PM	1	0	2	49.9	60.7	62.7	4.12	5.23	5.27
2 PM	2	1	3	50.8	62.3	64.6	4.20	5.37	5.43
3 PM	2	0	2	50.3	60.3	65.4	4.16	5.20	5.49
4 PM	0	0	3	51.3	60.8	65.8	4.24	5.24	5.53
5 PM	1	1	5	52.6	63.4	64.6	4.35	5.47	5.43
6 PM	0	1	2	51.9	65.1	59.7	4.29	5.61	5.02
7 PM	2	3	2	52.3	67.2	51.3	4.33	5.80	4.31
8 PM	2	1	0	53.0	68.1	40.5	4.39	5.87	3.40
9 PM	2	1	0	54.7	67.1	36.5	4.52	5.79	3.06
10 PM	2	2	0	53.1	67.7	32.9	4.39	5.84	2.76
11 PM	3	1	0	53.0	66.9	29.3	4.38	5.76	2.46
12 PM	2	0	0	52.0	65.5	26.1	4.30	5.65	2.20

TABLE 9. THE FREQUENCY OF OXIDANT PEAKS (FROP); THE MEAN OF DAYS AS PERCENT OF PEAK ON ANY DAY (MDPPAD); THE MEAN HOURLY OXIDANT CONCENTRATION IN PPHM (MNPCHR): AT SITES I, II, AND III FOR JULY 1975.

HOURS	FROP			MDP PAD			MNPCHR		
	I	II	III	I	II	III	I	II	III
1 AM	3	3	1	46.9	40.8	17.2	4.38	4.90	1.72
2 AM	1	0	1	45.8	40.1	15.9	4.27	4.81	1.59
3 AM	1	1	0	44.3	40.8	13.2	4.14	4.90	1.32
4 AM	0	2	0	44.5	38.8	11.0	4.15	4.65	1.10
5 AM	1	0	0	44.7	40.5	8.9	4.17	4.87	0.89
6 AM	0	0	0	42.0	39.6	7.1	3.92	4.76	0.71
7 AM	0	0	0	38.4	36.9	8.5	3.59	4.42	0.85
8 AM	0	0	0	35.3	35.6	22.1	3.30	4.27	2.21
9 AM	0	0	0	37.1	37.1	34.0	3.47	4.46	3.40
10 AM	0	0	1	37.2	38.8	43.5	3.47	4.66	4.35
11 AM	0	1	1	41.7	40.2	49.6	3.89	4.83	4.96
12 AM	0	2	2	43.7	41.2	56.0	4.08	4.95	5.60
1 PM	2	3	4	46.0	42.8	60.5	4.29	5.14	6.05
2 PM	2	1	9	47.2	41.6	61.9	4.40	4.99	6.19
3 PM	2	1	6	47.3	41.8	60.7	4.42	5.01	6.07
4 PM	0	0	3	46.0	42.0	59.5	4.29	5.04	5.95
5 PM	1	2	1	45.8	42.8	56.1	4.27	5.14	5.61
6 PM	0	2	1	43.9	42.4	47.7	4.09	5.08	4.77
7 PM	2	1	0	44.8	42.6	33.5	4.18	5.11	3.35
8 PM	1	1	0	46.6	42.7	27.8	4.35	5.12	2.78
9 PM	2	1	0	48.2	43.1	24.3	4.49	5.17	2.43
10 PM	2	3	0	45.6	44.1	21.9	4.26	5.30	2.19
11 PM	3	0	0	47.4	44.1	19.1	4.42	5.29	1.91
12 PM	2	0	0	46.3	41.6	17.2	4.32	4.99	1.72

TABLE 10. THE FREQUENCY OF OXIDANT PEAKS (FROP); THE MEAN OF LAYS AS PERCENT OF PEAK ON ANY DAY (MDPPAD); THE MEAN HOURLY OXIDANT CONCENTRATION IN PPHM (MNPKHR); AT SITES I, II, AND III FOR AUGUST 1975.

HOURS	FROP			MDP PAD			MNPKHR		
	I	II	III	I	II	III	I	II	III
1 AM	2	3	0	57.7	48.5	15.2	4.45	4.85	1.24
2 AM	0	1	1	59.2	47.4	15.5	4.57	4.74	1.26
3 AM	3	1	0	62.2	46.6	12.2	4.79	4.66	0.99
4 AM	1	0	0	61.7	45.5	11.6	4.76	4.55	0.94
5 AM	0	0	0	59.7	45.5	9.6	4.60	4.55	0.78
6 AM	0	2	0	58.8	45.5	9.7	4.54	4.55	0.79
7 AM	2	0	0	54.9	43.2	11.7	4.23	4.32	0.95
8 AM	0	0	1	49.3	41.2	23.8	3.80	4.12	1.94
9 AM	0	0	0	47.4	43.4	42.0	3.65	4.34	3.41
10 AM	0	0	1	48.5	43.8	50.8	3.74	4.38	4.14
11 AM	0	0	3	58.1	47.7	56.3	4.48	4.77	4.59
12 AM	4	2	4	63.8	48.7	62.3	4.92	4.87	5.07
1 PM	3	1	6	66.7	48.7	63.3	5.14	4.87	5.15
2 PM	3	1	8	65.8	47.6	65.7	5.07	4.76	5.35
3 PM	1	0	3	64.6	47.1	62.2	4.98	4.71	5.06
4 PM	1	0	3	63.9	47.5	60.6	4.93	4.75	4.94
5 PM	1	2	1	62.2	47.8	51.5	4.79	4.78	4.19
6 PM	0	1	0	60.1	48.1	38.2	4.63	4.81	3.11
7 PM	1	1	0	59.2	47.4	28.0	4.57	4.74	2.28
8 PM	0	0	0	57.5	48.6	27.6	4.43	4.86	2.24
9 PM	2	1	0	57.7	48.9	24.9	4.45	4.89	2.03
10 PM	1	4	0	57.3	50.0	22.6	4.42	5.00	1.84
11 PM	1	1	0	56.7	48.9	19.8	4.37	4.89	1.61
12 PM	1	3	0	55.1	49.0	17.1	4.25	4.90	1.40

TABLE 12. THE FREQUENCY OF OXIDANT PEAKS (FROP); THE MEAN OF DAYS AS PERCENT OF PEAK ON ANY DAY. (MDPPAD); THE MEAN HOURLY OXIDANT CONCENTRATION IN PPM (MNPKHR); AT SITES I, II, AND III FOR OCTOBER 1975.

HOURS	FROP			MDP PAD			MNPKHR		
	I	II	III	I	II	III	I	II	III
1 AM	5	2	1	46.6	41.9	16.5	3.86	3.70	1.29
2 AM	1	0	2	45.8	43.4	15.4	3.79	3.83	1.21
3 AM	1	1	0	45.3	42.2	14.6	3.75	3.72	1.15
4 AM	1	1	0	45.3	40.6	13.6	3.75	3.58	1.06
5 AM	1	0	0	43.7	41.8	12.4	3.61	3.69	0.98
6 AM	0	0	0	41.7	43.1	11.4	3.45	3.81	0.90
7 AM	1	0	0	41.5	43.4	10.7	3.43	3.83	0.84
8 AM	0	0	0	38.7	43.3	14.4	3.20	3.83	1.13
9 AM	0	0	1	39.0	43.7	30.8	3.23	3.86	2.42
10 AM	0	0	2	39.3	45.6	40.5	3.25	4.03	3.18
11 AM	0	2	1	44.0	47.4	42.7	3.64	4.18	3.36
12 AM	1	1	1	46.6	50.5	48.4	3.86	4.46	3.80
1 PM	0	1	2	49.2	51.6	49.2	4.07	4.56	3.86
2 PM	2	0	6	49.7	52.6	53.7	4.11	4.64	4.22
3 PM	2	1	4	49.9	53.4	52.9	4.13	4.72	4.15
4 PM	3	2	7	51.7	53.7	52.7	4.28	4.74	4.13
5 PM	2	2	0	51.2	52.4	44.5	4.24	4.62	3.49
6 PM	1	2	0	49.3	54.0	35.4	4.09	4.77	2.78
7 PM	1	1	0	48.4	48.6	29.1	4.01	4.29	2.28
8 PM	1	1	0	49.4	52.8	26.6	4.09	4.67	2.09
9 PM	1	2	0	50.6	50.3	24.2	4.19	4.44	1.90
10 PM	3	0	0	49.6	47.6	21.8	4.11	4.21	1.71
11 PM	0	0	0	48.5	44.5	19.8	4.02	3.92	1.56
12 PM	3	1	0	47.1	42.7	18.8	3.90	3.77	1.48

TABLE 11. THE FREQUENCY OF OXIDANT PEAKS (FROP); THE MEAN OF DAYS AS PERCENT OF PEAK ON ANY DAY (MDPPAD); THE MEAN HOURLY OXIDANT CONCENTRATION IN PPM (MNPKHR); AT SITES I, II, AND III FOR SEPTEMBER 1975.

HOURS	FROP			MDP PAD			MNPKHR		
	I	II	III	I	II	III	I	II	III
1 AM	4	3	0	52.7	51.1	18.5	3.42	2.98	1.40
2 AM	1	0	0	52.0	51.4	17.4	3.38	2.99	1.32
3 AM	0	1	0	54.5	50.9	16.3	3.54	2.97	1.23
4 AM	1	1	0	53.2	51.9	15.3	3.46	3.03	1.16
5 AM	2	0	0	51.6	52.2	13.8	3.35	3.05	1.04
6 AM	0	0	0	50.6	50.3	12.0	3.28	2.93	0.91
7 AM	0	0	0	50.8	20.9	11.2	3.30	2.97	0.85
8 AM	0	0	0	45.1	49.9	10.7	2.92	2.91	0.81
9 AM	0	0	0	42.5	50.2	19.4	2.76	2.93	1.47
10 AM	0	1	0	43.4	53.2	36.1	2.82	3.10	2.73
11 AM	1	1	0	45.1	57.9	44.7	2.93	3.38	3.39
12 AM	0	2	2	50.0	60.4	52.7	3.24	3.52	3.99
1 PM	0	2	4	56.1	61.5	56.7	3.64	3.58	4.29
2 PM	1	2	5	59.6	63.3	60.1	3.87	3.69	4.55
3 PM	1	5	7	60.1	64.8	60.0	3.90	3.78	4.54
4 PM	4	2	2	60.8	65.0	56.8	3.92	3.79	4.30
5 PM	2	1	1	60.5	63.8	47.5	3.94	2.72	3.60
6 PM	1	1	0	58.3	61.2	37.3	3.79	3.57	2.83
7 PM	3	2	1	58.0	59.9	30.5	3.76	3.49	2.31
8 PM	3	0	0	56.8	58.0	29.1	3.69	3.38	2.20
9 PM	0	1	0	54.9	58.1	26.4	3.57	3.38	2.00
10 PM	0	0	0	53.9	55.8	24.9	3.50	3.25	1.88
11 PM	0	0	0	54.1	54.8	21.9	3.51	3.20	1.66
12 PM	2	1	0	54.0	54.0	20.5	3.50	3.15	1.55

TABLE 13. THE FREQUENCY OF OXIDANT PEAKS (FROP); THE MEAN OF DAYS AS PERCENT OF PEAK ON ANY DAY (MDPPAD); THE MEAN HOURLY OXIDANT CONCENTRATION IN PPHM (MNPKHR); AT SITES I, II, AND III FOR NOVEMBER 1975.

HOURS	FROP			MDP PAD			MNPKHR		
	I	II	III ^a	I	II	III ^a	I	II	III ^a
1 AM	3	4		55.9	53.0		3.55	3.02	
2 AM	3	2		55.1	52.0		3.50	2.96	
3 AM	1	1		53.5	49.9		3.40	2.84	
4 AM	0	1		53.0	49.8		3.37	2.83	
5 AM	3	1		51.1	47.5		3.25	2.70	
6 AM	1	0		50.3	46.1		3.19	2.62	
7 AM	0	0		49.8	46.0		3.16	2.62	
8 AM	1	0		49.0	49.5		3.11	2.82	
9 AM	0	1		47.4	48.8		3.01	2.78	
10 AM	0	0		48.9	50.7		3.10	2.89	
11 AM	0	0		49.9	51.3		3.17	2.92	
12 AM	0	0		54.9	55.3		3.49	3.15	
1 PM	0	3		57.4	57.8		3.64	3.29	
2 PM	2	2		57.2	58.5		3.63	3.33	
3 PM	1	0		57.9	57.2		3.67	3.25	
4 PM	0	1		57.0	56.8		3.62	3.23	
5 PM	2	1		58.6	58.0		3.72	3.30	
6 PM	1	3		58.5	58.4		3.71	3.32	
7 PM	0	1		58.0	56.6		3.68	3.22	
8 PM	1	2		58.1	56.6		3.69	3.22	
9 PM	1	0		59.0	56.1		3.75	3.19	
10 PM	0	3		57.5	56.5		3.65	3.21	
11 PM	0	1		55.7	55.5		3.54	3.16	
12 PM	4	1		55.2	55.3		3.50	3.15	

^a No data taken at Site III.

TABLE 14. THE FREQUENCY OF OXIDANT PEAKS (FROP); THE MEAN OF DAYS AS PERCENT OF PEAK ON ANY DAY (MDPPAD); THE MEAN HOURLY OXIDANT CONCENTRATION IN PPHM (MNPKHR); AT SITES I, II, AND III FOR DECEMBER 1975.

HOURS	FROP			MDP PAD			MNPKHR		
	I	II	III ^a	I	II	III ^a	I	II	III ^a
1 AM	5	3		40.7	44.3		2.31	2.72	
2 AM	1	0		38.8	42.2		2.21	2.59	
3 AM	0	2		38.4	42.7		2.18	2.63	
4 AM	1	0		37.7	43.4		2.15	2.67	
5 AM	0	1		36.2	45.3		2.06	2.78	
6 AM	0	1		36.4	43.5		2.07	2.68	
7 AM	1	1		34.9	43.3		1.99	2.66	
8 AM	0	1		35.0	43.3		1.99	2.66	
9 AM	1	0		38.6	44.1		2.20	2.72	
10 AM	0	0		36.2	44.2		2.06	2.72	
11 AM	0	1		37.4	47.2		2.13	2.91	
12 AM	1	1		39.3	48.9		2.24	3.01	
1 PM	3	2		42.0	48.9		2.39	3.01	
2 PM	1	4		41.7	50.7		2.37	3.12	
3 PM	2	2		42.7	51.2		2.43	3.15	
4 PM	0	1		41.6	49.4		2.37	3.04	
5 PM	1	0		40.5	46.5		2.30	2.86	
6 PM	0	0		40.9	45.2		2.33	2.78	
7 PM	3	1		41.4	41.7		2.36	2.56	
8 PM	1	0		39.8	41.3		2.26	2.54	
9 PM	0	2		36.4	39.9		2.07	2.45	
10 PM	1	2		35.1	41.9		2.00	2.58	
11 PM	1	0		36.3	41.5		2.07	2.56	
12 PM	0	0		36.6	40.1		2.08	2.47	

^a No data taken at Site III.

TABLE 15. THE FREQUENCY OF OXIDANT PEAKS (FROP); THE MEAN OF DAYS AS PERCENT OF PEAK ON ANY DAY (MDPPAD); THE MEAN HOURLY OXIDANT CONCENTRATION IN PPHM (MNPKHR); AT SITES I, II, AND III FOR JANUARY 1976.

HOURS	FROP			MDP PAD			MNPKHR		
	I	II	III ^a	I	II	III ^a	I	II	III ^a
1 AM	3	0		35.6	51.0		2.75	2.43	
2 AM	2	1		35.6	50.0		2.75	2.39	
3 AM	0	0		36.4	52.0		2.82	2.48	
4 AM	1	1		38.0	53.5		2.93	2.55	
5 AM	1	0		39.2	53.1		3.03	2.53	
6 AM	0	0		35.7	52.6		2.76	2.51	
7 AM	0	1		33.8	50.7		2.62	2.42	
8 AM	1	0		33.3	50.6		2.57	2.42	
9 AM	1	0		36.2	54.4		2.80	2.59	
10 AM	1	0		36.2	59.7		2.79	2.85	
11 AM	0	4		36.6	60.7		2.83	2.89	
12 AM	0	1		39.4	62.9		3.05	3.00	
1 PM	2	2		43.0	64.9		3.33	3.10	
2 PM	1	1		43.6	61.4		3.37	2.93	
3 PM	3	4		45.4	61.8		3.51	2.95	
4 PM	1	0		43.7	60.4		3.38	2.88	
5 PM	1	0		41.7	60.7		3.22	2.89	
6 PM	0	0		41.9	59.7		3.24	2.85	
7 PM	0	0		40.9	57.8		3.16	2.75	
8 PM	2	0		40.1	51.6		3.10	2.46	
9 PM	0	0		40.3	49.3		3.11	2.35	
10 PM	0	1		40.1	54.0		3.10	2.58	
11 PM	2	3		40.4	52.7		3.12	2.51	
12 PM	3	1		39.9	51.9		3.09	2.47	

^a No data taken at Site III.

TABLE 16. THE FREQUENCY OF OXIDANT PEAKS (FROP); THE MEAN OF DAYS AS PERCENT OF PEAK ON ANY DAY (MDPPAD); THE MEAN HOURLY OXIDANT CONCENTRATION IN PPHM (MNPKHR); AT SITES I, II, AND III FOR FEBRUARY 1976.

HOURS	FROP			MDP PAD			MNPKHR		
	I	II	III ^a	I	II	III ^a	I	II	III ^a
1 AM	3	3		52.1	53.8		5.47	4.57	
2 AM	0	0		49.6	54.0		5.21	4.59	
3 AM	0	1		48.7	52.6		5.12	4.47	
4 AM	0	1		49.8	52.8		5.23	4.48	
5 AM	0	0		48.0	50.9		5.04	4.33	
6 AM	0	0		48.0	50.0		5.09	4.25	
7 AM	0	0		48.5	50.4		4.82	4.28	
8 AM	0	0		45.9	51.9		4.93	4.41	
9 AM	1	0		46.9	51.8		5.07	4.40	
10 AM	1	0		48.3	53.5		5.33	4.54	
11 AM	0	1		50.8	56.3		5.44	4.79	
12 AM	0	1		51.8	59.1		5.70	5.02	
1 PM	1	2		54.3	60.3		6.11	5.13	
2 PM	1	1		58.1	60.9		6.17	5.17	
3 PM	1	6		58.8	61.5		6.19	5.23	
4 PM	3	3		59.0	60.9		6.09	5.18	
5 PM	1	3		58.0	59.6		6.30	5.06	
6 PM	0	0		60.0	58.2		6.34	4.95	
7 PM	4	1		60.4	55.0		6.17	4.67	
8 PM	3	2		58.7	56.9		5.84	4.84	
9 PM	0	0		55.6	57.0		5.65	4.70	
10 PM	1	1		53.9	55.3		5.82	4.77	
11 PM	1	1		55.4	56.1		5.74	4.82	
12 PM	0	0		54.6	56.8				

^a No data taken at Site III.

TABLE 17. THE FREQUENCY OF OXIDANT PEAKS (FROP); THE MEAN OF DAYS AS PERCENT OF PEAK ON ANY DAY (MDPPAD); THE MEAN HOURLY OXIDANT CONCENTRATION IN PPHM (MNPKHR); AT SITES I, II, AND III FOR MARCH 1976.

HOURS	FROP			MDP PAD			MNPKHR		
	I	II	III ^a	I	II	III ^a	I	II	III ^a
1 AM	2	5		64.7	56.5		6.47	4.80	
2 AM	0	1		63.3	53.3		6.33	4.53	
3 AM	0	0		60.7	51.3		6.07	4.36	
4 AM	0	0		61.7	51.6		6.17	4.39	
5 AM	2	0		61.7	51.0		6.17	4.33	
6 AM	0	0		59.5	50.7		5.95	4.31	
7 AM	0	1		58.7	50.3		5.87	4.28	
8 AM	0	0		58.7	50.9		5.87	4.32	
9 AM	0	0		57.2	51.6		5.72	4.39	
10 AM	1	0		56.5	53.7		5.65	4.57	
11 AM	0	2		58.3	55.5		5.83	4.72	
12 AM	1	0		54.8	58.3		5.48	4.96	
1 PM	0	2		57.2	61.7		5.72	5.24	
2 PM	0	1		57.2	64.2		5.72	5.46	
3 PM	0	5		59.3	65.0		5.93	5.52	
4 PM	0	4		61.5	65.0		6.15	5.53	
5 PM	2	3		61.3	65.0		6.13	5.52	
6 PM	1	2		63.0	65.0		6.30	5.52	
7 PM	0	3		61.8	62.5		6.18	5.31	
8 PM	0	0		60.8	61.6		6.08	5.24	
9 PM	0	1		60.0	60.0		6.00	5.10	
10 PM	0	0		61.8	59.6		6.18	5.06	
11 PM	0	0		59.8	58.2		5.98	4.95	
12 PM	1	1		60.8	56.8		6.08	4.83	

^a No data taken at Site III.

Reviewing the frequency of oxidant peaks (FROP) over those months on the mountain Sites I and II indicate that there were generally four times during a day in which the mean oxidant concentration may have peaked for the day. They were early morning (3:00 a.m. to 6:00 a.m.), early afternoon (12:00 p.m. to 3:00 p.m.), in the evening (8:00 p.m. to 9:00 p.m.) and from (12:00 a.m. to 1:00 a.m.). This pattern became more evident when the mean of days as percent of peak on any day were examined.

At Site I the oxidant concentration decreased to a minimum at 8:00 a.m. to 9:00 a.m. then increased to a maximum at about 3:00 p.m. in the afternoon. During the summer months another peak occurred in the evening at about 9:00 p.m. At Site II the oxidant concentration decreased to a minimum at 6:00 a.m. to 7:00 a.m. then increased to a peak at 1:00 p.m. to 2:00 p.m. In the summer months another peak occurred in the evening around 9:00 p.m. and then another about 1:00 a.m.

In the winter months at both mountain sites maximum concentrations occurred in the afternoons and decreased to lower concentrations at night. These patterns of increasing and decreasing oxidant concentrations are also verified by examining the mean of days as percent of peak on any day (MDPPAD).

By examining the actual oxidant mean hourly oxidant concentration (MNPKHR) at the two mountain sites it is evident that there was little fluctuation in the oxidant concentration during the day. The mean concentration remained at relatively the same level over

all hours with variations from minimum to maximum being 1.0 to 1.5 pphm.

In the Shenandoah Valley Site III a very diurnal pattern was evident. In the valley site the mean oxidant concentration generally peaked in the afternoon hours from 12:00 p.m. to 2:00 p.m. The oxidant concentration decreased to a minimum at 6:00 a.m. then increased at an initial rate of approximately 1 pphm per hour, to a maximum at about 2:00 p.m. At about 3:00 p.m. the oxidant concentration began to decrease gradually at a rate slower than that of the increase period, extending into the early morning hours. By 9:00 p.m. a substantial decrease in oxidants usually had occurred in the valley site. The change in oxidant concentration in the valley site from minimum to maximum during a typical day was from 1.0 pphm to 6.0 pphm. The mean hourly oxidant concentration occurring in the afternoon in the valley site exceeded maximum concentrations found on the mountain site by 1.0 to 1.5 pphm, during the summer months.

White Pine Studies; Field Trees

At Site I, 21 eastern white pine within a planted 15-year-old stand were rated into one of three symptom expression classes (sensitive, intermediate, and tolerant) with seven trees per class as described earlier. Determination of sensitivity was based on symptom expression of the one-year-old needles. Symptom expression was rated according to the following scale: 1) chlorotic spot; 2) chlorotic mottle; 3) chlorotic band; 4) chlorotic tip; 5) necrotic spot; 6) necrotic band; and 7) tip burn. This sequence of symptom

expression was chosen because it has been proposed by other researchers as being the sequence of symptom progression and order of increasing expression of severity of the lesion.

The severity index of needle injury (number of the symptom x percent injury) for the sensitive, intermediate, and tolerant trees are found in Tables 18, 19, and 20, respectively. The mean severity index of all three classes is presented in Table 21 and graphically in Figure 9.

The injury to the sensitive class trees was severe, being expressed mainly as tip necrosis which progressed distally toward the base of the needle from the tip; later in the growing season chlorotic mottle developed over all of the remaining live tissue. The intermediate class trees expressed chlorotic spots and in severe cases chlorotic mottling. The tolerant trees remained essentially free of air pollution symptoms. A few chlorotic spots were noted and one tree sustained injury from aphids.

The severity index increased in all intermediate class trees (with the exception of tree 7) and all sensitive class trees from July 1 to July 10, 1975 as a result of the high levels of oxidants transported into these mountains on July 2 and 3. From July 1 to July 10, 1975 the mean severity index, of the intermediate class trees increased from 2.27 to 32.92, and the sensitive class trees increased from 105.59 to 197.83, showing a substantial increase in the level of injury to these trees.

TABLE 18. SEVERITY INDEX OF NEEDLE INJURY DUE TO OXIDANT OCCURRING ON SENSITIVE SITE I EASTERN WHITE PINE FIELD TREES DURING THE 1975 GROWING SEASON.

Tree No.	6/14	6/20	7/1	7/10	7/21	8/1	8/12
	Severity Index ^a						
1	.35	4.95	34.90	272.90	447.49	476.0	465.0
2	7.00	19.75	31.90	128.55	156.0	154.0	154.9
3	29.40	177.45	235.26	224.80	180.75	259.60	237.0
4	2.80	9.55	42.45	83.90	89.00	94.20	158.5
5	50.40	126.05	172.75	287.45	308.40	318.11	311.50
6	31.80	70.25	174.15	295.87	306.7	291.6	273.45
7	1.96	51.40	47.70	91.35	101.8	166.85	164.80

^a Severity Index = type of symptom X percent injury.

TABLE 19. SEVERITY INDEX OF NEEDLE INJURY DUE TO OXIDANT OCCURRING ON INTERMEDIATE SITE I EASTERN WHITE PINE FIELD TREES DURING THE 1975 GROWING SEASON.

Tree No.	6/14	6/20	7/1	7/10	7/21	8/1	8/12	8/31
Severity Index ^a								
1	.85	1.20	1.25	2.10	1.55	2.30	1.55	4.20
2	1.40	3.50	3.60	18.55	25.25	33.90	28.35	192.55
3	0	.05	.05	.15	.20	.20	.20	.20
4	.60	4.50	7.65	14.55	15.10	15.15	17.0	17.0
5	0	1.40	1.35	192.0	192.0	192.0	192.0	192.0
6	0	.60	.60	2.40	5.60	3.20	3.20	3.20
7	0	.55	1.40	.75	24.0	24.0	24.0	24.0

^a Severity Index = type of symptom X percent injury.

TABLE 20. SEVERITY INDEX OF NEEDLE INJURY DUE TO OXIDANT OCCURRING ON TOLERANT SITE I EASTERN WHITE PINE FIELD TREES DURING THE 1975 GROWING SEASON.

Tree No.	6/14	6/20	7/1	7/10	7/21	8/1	8/12	8/31
Severity Index ^a								
1	0	.15	.15	.05	.65	.40	.40	.40
2	0	.60	.60	.90	.90	.90	.90	.90
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	.40	.40	.40	.40	.40
6	0	.75	2.10	3.15	4.45	4.45	4.45	4.45
7	0	0	0	0	0	0	0	0

^a Severity Index = type of symptom X percent injury.

TABLE 21. MEAN SEVERITY INDEX OF NEEDLE INJURY DUE TO OXIDANT OCCURRING ON SENSITIVE, INTERMEDIATE, AND TOLERANT SITE I EASTERN WHITE PINE FIELD TREES DURING THE 1975 GROWING SEASON.

Tree Class	6/14	6/20	7/1	7/10	7/21	8/1	8/12	8/31
Severity Index ^a								
Sensitive	17.67	65.63	105.39	197.83	227.16	251.48	252.16	
Intermediate	.41	1.68	2.27	32.92	37.67	38.67	38.04	61.88
Tolerant	0	.21	.41	.64	.91	.88	.88	.88

^a Severity Index = type of symptom X percent injury.

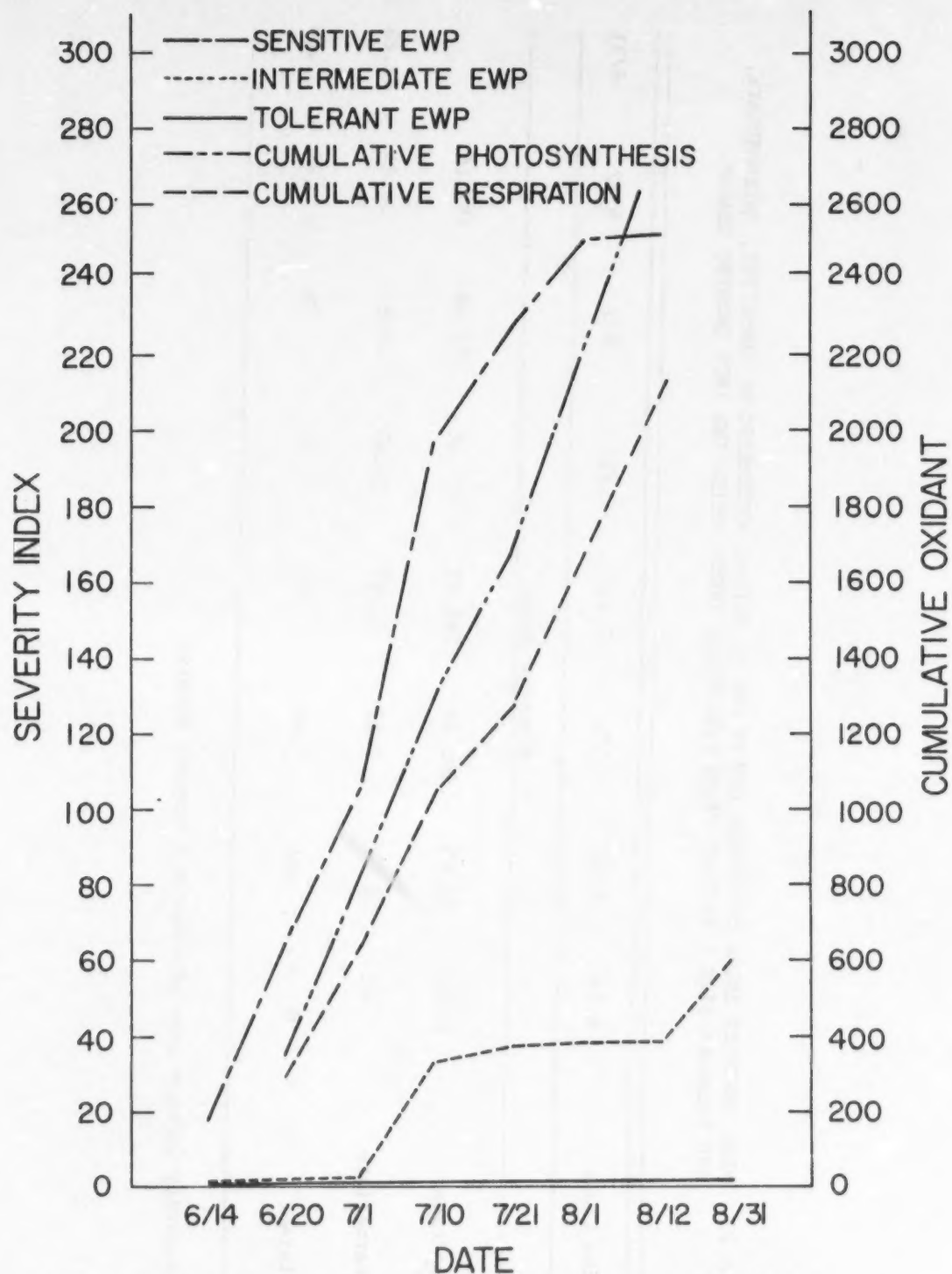


Figure 9. Comparison of cumulative oxidant concentration during photosynthesis and respiration vs. the severity index of needle injury of the Sensitive, Intermediate, and Tolerant, Site I white pine field trees over the 1975 growing season.

Eastern White Pine; Field Trees, Statistical Analyses

Figure 9 shows the relation of the mean severity index of the sensitive, intermediate and tolerant class trees to cumulative oxidant concentrations during periods of photosynthesis and respiration. Cumulative oxidant during photosynthesis and respiration as described earlier are cumulative amounts of mean hourly oxidant concentrations over specific time periods during the day as defined in the computer analysis. Photosynthesis was considered to predominantly take place within the hours of 7:00 a.m. to 9:00 p.m. and respiration takes place over all other hours, 9:00 p.m. to 7:00 a.m.

Photosynthesis was defined to take place during the hours when the stomates of the needles would be open; when the tissue would be most susceptible to injury. Noting that the curve of the mean severity index of the sensitive class trees was closely related to the cumulative oxidant during photosynthesis a statistical analysis was run to investigate the degree of linear relationship. The correlation coefficient r an estimator for the correlation coefficient was computed.

A linear regression analysis was also chosen to establish a statistical model from which predictions of increased injury from increased concentrations of oxidants would be possible, Figure 10.

The correlation coefficient r , for the sensitive trees (Figure 9), was 0.86, indicating a high degree of linear association. Also, a correlation coefficient of 0.48 and 0.50 was determined for the intermediate and tolerant trees, respectively.

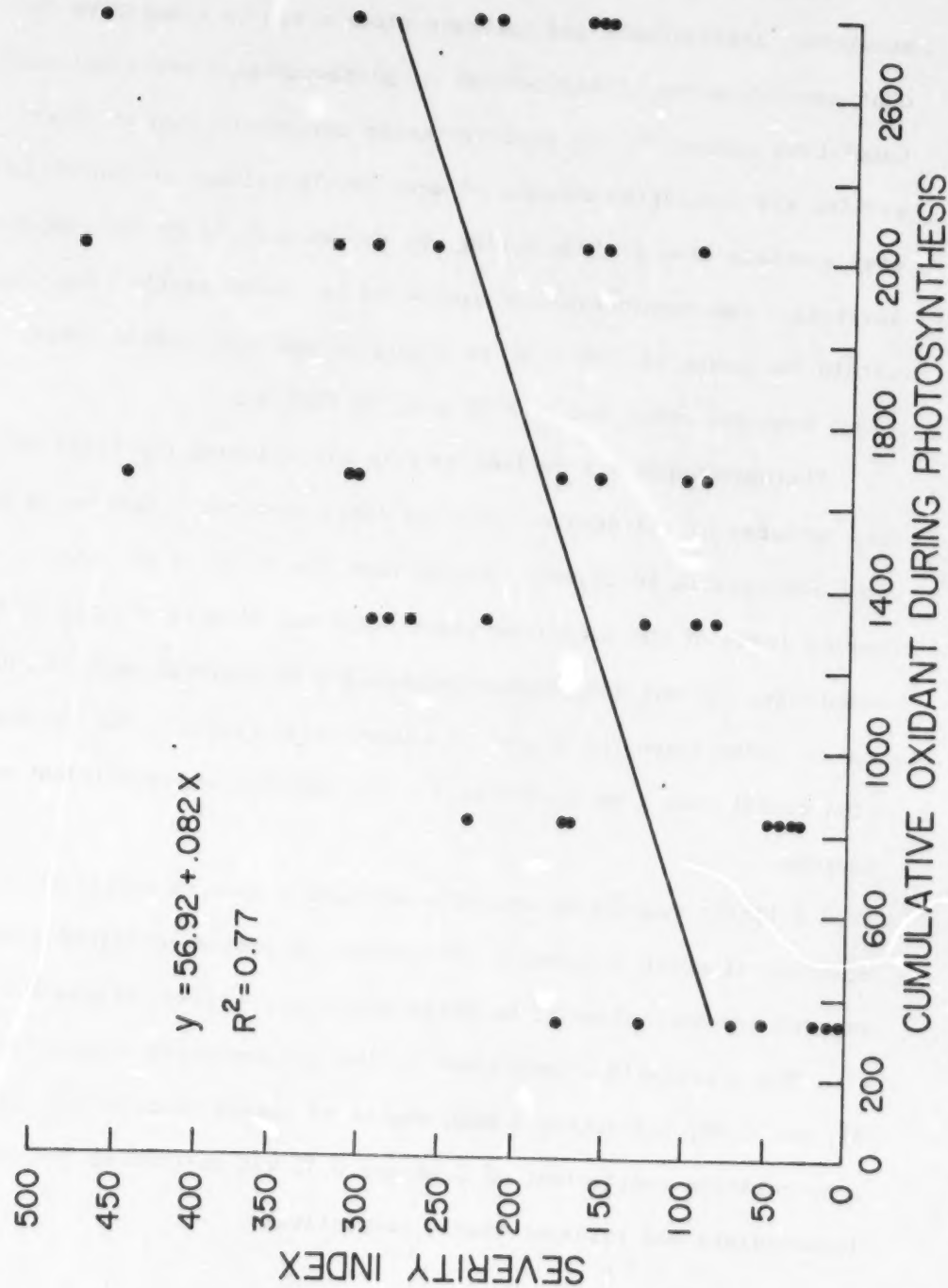


Figure 10. Linear regression analysis of Site I, sensitive field trees.

The regression analysis yielded a regression line of $Y = 56.92 + 0.082X$, with an R^2 value of 0.77, where Y is the mean of severity index of needle injury and X is the cumulative oxidant during photosynthesis.

Eastern White Pine Studies; Grafted Trees

The results of the grafted tree studies for Sites I, II, and III are presented in Tables 22, 23, and 24, respectively. The sensitive lines sustained severe injury while the tolerant lines remained free of air pollution symptoms. The W-4-S grafts were the most severely injured developing tip necrosis which progressed distally until 80 to 90% of the tissue was necrotic. Later in the summer the remaining tissue on these grafts developed chlorotic mottling.

The W-4-S grafts at Site II were initially the most severely injured which correspond well with the high levels of oxidant concentrations recorded at that site. The W-4-S grafts at Sites I and III did not sustain initial injury as severe as those at Site II, but continued to develop symptoms through the summer months. The W-1-S grafts at all three sites showed increases in lesion development by the end of the first week of July following the period of high oxidant concentrations.

The W-1-S grafts were not as sensitive as the W-4-S grafts but generally developed chlorotic spots and bands which later in the summer coalesced to form chlorotic mottling. The W-1-S grafts at Site I initially sustained more injury expressed as tip necrosis than at the other two sites. The death of the grafts at Site I was attributed to

TABLE 22. LEVEL OF INJURY DUE TO OXIDANT TO FOUR LINES OF GRAFTED EASTERN WHITE PINE TREES THROUGH THE 1975 GROWING SEASON, SITE I.

Sensitive Tolerant	5/30	6/5	6/12	6/19	7/7	7/21	8/7	8/12	8/31	9/16
W-4-S	90% TB	100% TB					CM			DEATH
W-4-S	0	0	0	C	80% CB	100% CM	>S			
W-4-S	0	0	0	C	60% CB	90% CB	100% CM			DEATH
W-4-S	70% TB		90% TB		>S	CM	CM			
W-4-S	50% TB	70% TB	90% TB	>S	>S					
W-4-S	30% TB	50% TB	90% TB		>S			CM		
W-1-S	0	0	30% TB	80% CB	50% TB	CM	>CM		DEATH	
W-1-S	50% TB	80% TB	90% TB	100% TB			CM			
W-1-S	0	0	C	100% CS	>S					
W-1-S	0	0	C	100% CB	>S					
W-1-S	0	0	10% TB							
W-1-S	0	0	C	C	C	>S	DEATH			
PA-10-T	0	0	0	0	0	10% CM	50% CB	0	0	0
PA-10-T	0	0	0	0	0	0	0	0	0	0
PA-10-T	0	0	0	0	0	0	0	0	0	0
PA-10-T	0	0	0	0	0	0	0	0	0	0
PA-10-T	0	0	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0	0	0

C = Chlorotic CB = Chlorotic banding NB = Necrotic banding >S = Increase in severity
CS = Chlorotic spots CM = Chlorotic mottle TB = Tip burn

TABLE 23. LEVEL OF INJURY DUE TO OXIDANT TO FOUR LINES OF GRAFTED EASTERN WHITE PINE TREES THROUGH THE 1975 GROWING SEASON, SITE II.

Sensitive Tolerant	6/1	6/13	6/18	6/23	7/3	7/11	7/23	8/2	8/13	8/28	9/16
W-4-S	1% TB	20% TB	10% NB						CM		
W-4-S	70% TB	90% TB							CM		
W-4-S	70% TB	90% TB	>S						DEATH		
W-4-S	100% TB		>S						DEATH		
W-4-S	100% TB	>S	>S						CM		
W-4-S	100% TB	>S	>S						CM		
W-1-S	100% TB	>S							CM		
W-1-S	0	0	C	5% CS	40% CB			60% CB			
W-1-S	0	0	20% CB			90% CB					
W-1-S	5% TB		80% CB					100% CM			
W-1-S	0	0	C	C	C	70% CS			DEATH		
W-1-S	1% TB		10% TB		80% CB	100% CB			CM		
PA-10-T	0	0	0	0	0	0	0	0	DEATH		
PA-10-T	0	0	0	0	0	0	0	0	0	0	0
PA-10-T	0	0	0	0	0	0	0	0	0	0	0
PA-10-T	0	0	0	0	0	0	0	0	0	0	0
PA-10-T	0	0	0	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0	0	0	0

C = Chlorotic

CS = Chlorotic spots

CB = Chlorotic banding
CM = Chlorotic mottle

NB = Necrotic banding
TB = Tip burn

>S = Increase in severity

TABLE 24. LEVEL OF INJURY DUE TO OXIDANT TO FOUR LINES OF GRAFTED EASTERN WHITE PINE TREES THROUGH THE 1975 GROWING SEASON, SITE III.

Sensitive Tolerant	6/9	6/18	6/23	7/9	7/22	7/28	8/10	9/5
W-4-S	100% TB	>S	50% CB	>CB	>S			CM
W-4-S	60% TB	>S			70% CB		CM	
W-4-S	70% TB		>S	50% CS	30% CB	90% CB	CM	
W-4-S	30% TB	10% CB	80% CB		CM			
W-4-S	80% TB	90% TB	>S	70% TB			50% CB & CM	
W-4-S	50% TB	20% CB	30% CB	90% CB			CM	
W-1-S	C	80% CB		100% CB		20% CM	60% CM	
W-1-S	C	80% CB	90% CB	100% CB		20% CM	50% CM	
W-1-S	C	80% CB					80% CM	
W-1-S	0	80% CB				CM	100% CM	
W-1-S	0	0	100% CB					100% CM
W-1-S	0	30% CB	50% CB	70% CB		100% CM	>S	DEATH
PA-10-T	0	0	0	0	0	0	0	0
PA-10-T	0	0	0	0	0	0	0	0
PA-10-T	0	0	0	0	0	0	0	0
PA-10-T	0	0	0	0	0	0	0	0
PA-10-T	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0
W-5-T	0	0	0	0	0	0	0	0

C = Chlorotic

CS = Chlorotic spots

CB = Chlorotic banding

CM = Chlorotic mottle

NB = Necrotic banding

TB = Tip burn

>S = Increase in severity

severe defoliation as result of oxidant injury. The death of the grafts at Site II was the result of girdling of the stems by field mice.

SECTION VIII

DISCUSSION

Oxidant Concentrations and Meteorology

Before the mid 1960's, high levels of oxidant had not been observed in rural environments (26). The high levels of rural oxidants reported in this study confirm findings of other researchers (2, 3, 5, 10, 11, 28, 33, 34) and have also been confirmed by the Virginia State Air Pollution Control Board (personal communication).

These data further indicate that transport of oxidant and oxidant precursors from the urban environment to the rural environment is possible under appropriate meteorological conditions. Under such conditions, high levels of pollutants can be transported several hundred miles as was reported in this study. Under the influence of the determinant meteorological conditions preceeding July 3, 1975, it is possible that air pollutants were transported into southwestern Virginia from areas as far away as New York City. If the air was flowing in another direction the results would have been different. On July 2, 1974, Cleveland and Kleiner (11) recorded high levels of ozone in Connecticut and Massachusetts, the result of transport from New York City. They demonstrated transport from the Camden-Philadelphia urban complex to distances up to 49 km. Ozone transport has been demonstrated to the Mineral King Valley of California (a rural site) from the Central Valley (an urban site) by Miller (34).

Altshuller (1) has reported that the Los Angeles ozone plume extends at least 100 miles downwind and conjectures that if plumes

of other cities have similar dimensions, the spacing of cities in the Eastern and Midwestern U. S. is such that the plume of an upwind city could overlap a downwind urban area. The results of our study further support this conjecture.

Under less adverse conditions as those described for July 3, 1975, the oxidant concentrations in southwestern Virginia have been shown to be influenced by urban environments through the association of increases in oxidant concentrations and winds from the north and northeast. To the north and northeast of southwestern Virginia lie the urban complexes of Philadelphia, Baltimore, and Washington, D. C. Although there are no specific times when the air can be said to be flowing from one of these areas into southwestern Virginia, under appropriate meteorological conditions the possibility is highly probable.

Increases in oxidant concentrations were also associated with the presence of high pressure systems. Such systems as described earlier enhance the generation of photochemical oxidants under open skies. In the Ohio Valley in 1975, similar increases in oxidant concentrations were reported when the central region of a high pressure system moved into the region (5).

It has been hypothesized that the types of reactions generating oxidants in the rural atmosphere are similar to those generating oxidants in the urban atmosphere (29, 40), as was described earlier. However, natural synthesis alone in the rural environment could not singly account for the levels of oxidants being reported. The data

plotted in Figures 7 and 8 indicate an increase in oxidant concentrations over a 13 to 14 year period (7). The work by Berry (7) may represent what the normal background levels of oxidants are for a remote forested area.

The urban reaction system has a far greater emission intensity of oxidant precursors which are responsible for the undesirable effects of photochemical smog in metropolitan areas. The significance of this urban reaction system is the probability of the contribution of a component precursor that would contribute to oxidant synthesis in the rural environment. This idea has recently been supported by Chameides and Stedman (9). They presented a theoretical model showing that significant amounts of excess ozone may be produced through the interaction of anthropogenic NO_x from urban centers with the ambient methane oxidation chain. Implying that the high abundances of NO_x commonly found in urban areas may ultimately cause high ozone levels in surrounding rural areas. As air moves from the urban to the rural environment, the HC to NO_x ratio increases. It has been shown that as this ratio increases the oxidant dosage increases (23). This appears to be the case in a rural environment. As an air mass moves from an urban area to a rural area, it would encounter higher levels of natural hydrocarbons (38). Their recently shown reactivity (29, 40) supports the possibility of higher levels of oxidants in rural areas to be maintained over longer periods.

If these premises are correct, then the rural environment is subject to a photochemical oxidant generating system that is highly

dependent on the sun's energy and should show systematic increases and decreases over large geographical regions. This is the situation in the mountainous areas of southwestern Virginia.

Oxidant Concentrations in Mountainous Terrain

Berry (7) monitored oxidant concentrations and reported differences between a valley and mountaintop site. In the valley site, the highest concentrations occurred during the day; they reached a maximum at 2:00 p.m. On the mountaintop the highest concentration occurred at night. Worth, Ripperton, and Berry (46) reported that the daily mean oxidant concentrations on a mountaintop during a summer season were higher by a factor of 2 to 3 than mean values for a valley site. Maximum concentrations at the mountain site occurred at night and maximum concentrations at the valley site occurred in the afternoon.

The findings presented in the present study are also similar in that the daily mean oxidant concentrations were higher at the mountain site than at the valley site throughout the summer months. The highest hourly mean concentrations occurred at night in the mountain sites and in the afternoon in the valley sites (MDPPAD). In the winter months, higher oxidant concentrations at the mountain sites were recorded during the afternoon than at night. They then decreased to slightly lower levels at night (MDPPAD).

It is important to note that the mean hourly oxidant concentration occurred in the afternoon in the valley site and that it can exceed maximum concentrations found on the mountain sites in the

afternoon by 1.0 to 1.5 pphm. These differences suggest that the possibility of acute foliar injury by high oxidant dosages is more likely in a valley site when precursors are present.

It appears that a good portion of the oxidant present at ground level in the valley site is displaced to higher altitudes at night by cool air draining down in the mountain slopes. The frequency of oxidant peaks (FROP) has shown that on the mountain sites a corresponding peak oxidant concentration will occur in the early evening.

In support of oxidant movement from valley areas into low level inversion layers, Kroening and Ney (27), have found higher oxidant concentrations above surface inversions than at ground level at night. Lea (28) also found ozone rich layers occurring within elevated but low level inversion layers.

The drop in oxidant concentration in the valley at night is probably also partly due to oxidant destruction at the surface with the ground acting as a sink, also suggested by Kroening and Ney (27).

The mean hourly oxidant concentration in pphm (MNPKHR) showed that the oxidant concentration remained essentially at the same level over all hours of the day on the mountain sites. The implication is that a sink of high oxidant concentration exists in the higher elevations of the mountains of southwestern Virginia.

Lea (28) reported that ozone rich layers occurred within elevated but low level inversion layers. He suggested that the high ozone concentrations observed aloft at Pt. Muger, California, could be attributed to precursors originating in the Los Angeles area.

If the premises made in the previous discussion section are correct in that the urban reaction system is contributing a component precursor to maintain high levels of oxidant over longer periods of time, then the oxidant rich layers found in the higher elevations of the mountains of southwestern Virginia may be the result of precursors advected into the troposphere from urban complexes along the coastal megalopolis.

Effects of Oxidants on Eastern White Pine

Evidence that needle blight of eastern white pine is caused by an atmospheric agent was presented by Berry in 1961 (6). In this study, Berry showed that sensitive trees developed fewer symptoms than previously when moved to an area where fewer sensitive trees occurred. When sensitive and tolerant scions were grafted to sensitive and tolerant stocks, 91% of the surviving trees persisted in their original condition regardless of the condition of the trees on to which they were grafted. Typical needle blight symptoms were produced on sensitive grafts when fumigated at 10 ppm ozone for 2 hours. Tolerant grafts from the field remained tolerant when fumigated at the same dosage.

Since this time, numerous investigators have documented the sensitivity of eastern white pine to air pollutants (13, 14, 17, 18, 20, 25, 32, 36).

Costonis and Sinclair (14) found that needle blight of eastern white pine in field and laboratory studies to be a syndrome of acute and chronic ozone injury. Monitoring ozone in a natural 10-15-year-old

stand of eastern white pine in central New York, they found that concentrations of 3 pphm for 48 hours to 7 pphm for 4 hours caused acute injury to current season needles on field and potted trees.

In the present study the threshold level of 4 pphm was equaled or exceeded at Site I for 385 hours or 59.5% of total hours, 302 hours or 50.4% of total hours, and 441 hours or 68.1% of total hours, for June, July, and August 1975, respectively. The threshold level of 6 pphm was equaled or exceeded at Site I for 38 hours or 5.9% of total hours, 54 hours or 9.0% of total hours, and 80 hours or 12.4% of total hours, for June, July, and August 1975, respectively. Similar high levels of oxidants (Table 4 and 5) were recorded at Sites II and III.

As reviewed earlier, Morris (36) working in Rockbridge County, Virginia in 1973, showed that 13 of 15 mature eastern white pine trees declined after two years of exposure. Six of the 13 trees died after what appeared to be a result of three consecutive exposures.

In this present study, a high degree of linear association was found between the severity index of needle injury of the sensitive Site I field trees and cumulative amounts of oxidants monitored during the hours of photosynthesis; further documenting the sensitivity of eastern white pine to air pollutants. Correlations run between the severity index of the Site I intermediate and tolerant Site I field trees and cumulative amounts of oxidants monitored during hours of photosynthesis did not show a close linear relationship. Also, a regression analysis yielding an equation of $Y = 56.92 + 0.082X$

between the severity index of needle injury (Y) of the Site I sensitive trees and cumulative oxidant during photosynthesis (X) was determined. This equation can be used to predict increased injury from increased levels of oxidants; however, it is only valid over oxidant concentrations of 3 to 12 pphm. Whether or not the injury was caused by ozone alone or other oxidants acting synergistically, cannot be determined since other pollutants were not monitored. The possibility has recently, however, been shown by a number of researchers (13, 18, 25).

Costonis (13) and Houston (25) have shown that low levels of SO_2 can cause injury to sensitive lines of eastern white pines. Also, low levels of SO_2 and O_3 can synergistically promote early symptom development on sensitive eastern white pines.

In a study similar to the present study, Costonis (13) observed that on sensitive and intermediate eastern white pine field trees all needles within a fascicle were not equally affected by a given exposure to ozone. The injury was not uniform on different fascicles or branches. Many symptoms could be observed on some needles even within a single fascicle.

The injury observed with the sensitive and intermediate Site I field trees was more uniform than described by Costonis (13). Generally, uniform tip necrosis developed on the sensitive Site I field trees followed later by development of chlorotic mottle on the remaining live tissue. The intermediate Site I field trees generally developed uniform chlorotic spots followed by chlorotic mottle on

those severely injured trees. These studies were similar in that many symptoms could be found on the same needle and needles within a single fascicle.

Costonis (13) observed that severely injured current year's needles of highly susceptible trees may be cast singly or in fascicles as early as the latter part of August. Usually, however, they were retained until about mid-July of the next growing season.

Similar results were observed in this study with both the sensitive and intermediate Site I field trees and also with the sensitive (W-4-S) grafted trees. A few of the sensitive (W-4-S) grafted trees developed severe defoliation as a result of oxidant injury and subsequently died. Some current seasons needles were cast from severely injured sensitive Site I field trees by mid-August. The one-year-old needles of the intermediate Site I field trees began dropping by mid-July and continued through August. By October only the current seasons needles were present.

Normally, Eastern white pine trees retain their needles until the second growing season of the following Spring (22).

All three of the needle injuries described by Hepting and Berry (24), emergence tipburn, postemergence acute tipburn, and postemergence chronic tipburn, described earlier were observed in this study. Emergence tipburn was observed early in June on the sensitive class Site I field trees. The remaining injury sustained by these trees is the result of postemergence chronic tipburn and one known incident of postemergence acute tipburn. As described earlier, postemergence

acute tipburn is the sudden browning of some or all of the foliage often involving the entire length of the needles. Needles may be shed in quantity shortly after the injury appears. The high levels of oxidant monitored on July 3, 1975 resulted in a postemergence acute tipburn of the sensitive Site I field trees and also to mature white pine trees growing in the Shenandoah Valley, and to trees growing along the Blue Ridge Parkway in Floyd County, Virginia. A week to 10 days following this period of high oxidant levels, several moderately tip-burned eastern white pines in Floyd County were observed to be dropping large numbers of 1 year old needles.

Using the sensitive W-1-S grafts in field experiments in 1961, Berry was able to distinguish two attacks of emergence tipburn as a result of two rises in atmospheric oxidant concentration.

The results with the same lines grafted material used in this study were the same with the exception that new lesion developments on the sensitive W-1-S grafts could not be associated with specific increases in oxidant concentrations due to the high level of oxidants occurring most of the time.

Initial symptom development observed on the sensitive W-4-S grafts was similar to that described by Linzon (30). Lesion development began by collapse of tissue on the stomata-bearing faces of the needle. Within the injured area faint pinkish spots give way to orange-red necrotic bands which spread distally to the needle tips. After continued exposure to acute levels, the necrosis spreads distally toward the needle base.

Progression of symptoms in less sensitive trees, W-1-S sensitive grafts and the intermediate class Site I field trees was different. Generally the first symptoms to occur are chlorotic spots or chlorotic bands. Later in the growing season as a result of continued exposure to acute and chronic levels of oxidants, these chlorotic areas coalesced to form a mottling symptom. These observations may indicate that a re-evaluation of the rating scale as an indicator of symptom progression and severity is in order.

The results from the study by Miller (33) in the San Bernardino National Forest in southern California have shown that photochemical oxidants are causing severe damage to ponderosa pine, deteriorating average trees at alarming rates. This continued exposure to oxidant air pollution raises many important questions about the reproductive and vegetative vigor of the conifer species, their ability to compete successfully with other associated vegetation, and to withstand diseases, insects, and extremes of the physical environment.

Oxidant air pollution has been shown by Miller (33) to be one of several competing mortality factors which acts to predispose sensitive trees to root diseases and subsequently to attack and kill by bark beetles.

The results of this study have shown that oxidant sensitive and intermediate eastern white pine trees growing in the mountainous areas of southwestern Virginia, are under stress from acute and chronic levels of oxidant air pollution.

SECTION IX

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SECTION X

APPENDIX I

APPENDIX A - Fortran program used in the computer analysis.

```

INTEGER ATRFM(5), CUMDAS
INTEGER POLPOR(3, 15)/45*0/, TOTPOL(3)/3*0/, TOT(3)/3*0/
REAL PLRPOR(3, 15)/45*0./
INTEGER AMPM(24)/12*'AM', 12*'PM'/, NUMDAS(3)/3*0/
INTEGER*2 HOUR(24), BGNPHO, ENDPHO
INTEGER*2 NMDAS(3)/3*0/, NMDA10(3)/3*0/, NMDA15(3)/3*0/
INTEGER*2 NUMBER, SITE, MO, DA, YR
IR10/0/, PKHR5/0/, PKHR/0/, FRP/LZ(3, 24)/72*0/, FRP010(3, 24)/72*0/, FR
2P05(3, 24)/72*0/, FRPO(3, 24)/72*0/, DAL, DA2, YR1, YR2
INTEGER EPHOP1, BPHOM1
REAL PCPO(3, 24)/72*0./
REAL PCUM0Z(100, 3, 24)/7200*0./, TCUM0Z(100, 3, 24)/7200*0./,
IRCUM0Z(100, 3, 24)/7200*0./
REAL OZONE(24), PKOZ15/0./, PKOZ10/0./, PKOZ5/0./, PKOZ/0./, MKOZDA/0.
1/, SUMOZO(3, 24)/72*0./, MAXOZ(3)/3*0./, SMMXOZ(3)/3*0./, PCP015(
33, 24)/72*0./, PCP010(3, 24)/72*0./, PCP05(3, 24)/72*0./, MNPKHR(3, 24)/
42*0./, MDPPAD(3, 24)/72*0./, MDPMDP(3, 24)/72*0./, TCOOAH(3, 24)
5 /72*0./, RCOOAH(3, 24)/72*0./, PCOAH(3, 24)/72*0./, TCOOAH(
63, 100)/300*0./, RCOOAH(3, 100)/300*0./, PCOAH(3, 100)/300*0./
REAL MODPO(3), MEAN
COMMON ATRFM, MO1, MO2, DA1, DA2, YR1, YR2
CALL TITLE
CALL TABLE1
CC*****
CC READ THE TRANSFORM: INITIAL AND FINAL MONTH, DAY, AND YEAR: AND
CC THE NUMBER OF DAYS TO REPORT CUMULATIVE OZONE: BLANK REPORTS ALL
CC*****
CC READ (5, 459) ATRFM, MO1, DA1, YR1, MO2, DA2, YR2, CUMDAS, BGNPHO, ENDPHO
459 FORMAT (5A4, 2X, 3(12), 4X, 312, 2X, 12, 3X, 12, 3X, 12)
CC*****
CC INITIALIZE THE VARIABLE I FOR PRINTING THE HOURS 1-12 AM & PM
CC*****
DO 834 I=1, 12
HOUR(I)=I

```

```

J=I+12
HOUR(J)=I
834 CONTINUE
CC*****
CC READ TWO DATA CARDS
CC*****
125 READ(5,150,END=225)NUMBER,SITE,M0,DA,YR,(OZONE(I),I=1,12) NMBER2,
I(OZONE(I),I=13,24)
150 FORMAT (14,I1,I2,I2,I2,4X,12F5.0/14,11X,12F5.0)
N=0
OZSQRD=0.0
SIGOZO=0.0
CC*****
CC COUNT THE NUMBER OF TIMES OZONE IS WITHIN GIVEN LEVELS
CC*****
DO 313 J=1,24
I=OZONE(J)+1.
POLPOR(SITE,I)=POLPOR(SITE,I)+1
313 CONTINUE
DO 737 IRT=1,24
CC*****
CC CONVERT THE OZONE DATA. THE TRANSFORM CARD MAY BE REPLACED FOR
CC A DIFFERENT TRANSFORM.
CC*****
OZONE(IRT)=OZONE(IRT)*1.
CC*****
OZSQRD=OZSQRD+OZONE(IRT)**2
SIGOZO=SIGOZO+OZONE(IRT)
N=N+1
CC*****
CC TEST FOR THE PEAJ OZONE READING OF THE DAY
CC*****
IF (MXOZDA.GE.OZONE(IRT))GO TO 737
MXOZDA=OZONE(IRT)
PKHR=IRT

```

```

737 CONTINUE
  MEAN=SIGOZO/N
  VAR=(OZSQRD-(SIGOZO**2)/N)/(N-1)
  STDDEV=SQRT(VAR)
CC*****
CC  WRITE THE VALUES FOR TABLE ONE
CC*****
  WRITE(6,350) NUMBER,SITE,MO,DA,YR,(OZONE(I),I=1,12),NUMBER2,
350 FORMAT (1H, 14,1X,11,1X,12,1X,12,1X,12,5X,12(1X,F5.2)/1H ,14,16X,
112(1X,F5.2),T100,F4.1,T115,F6.1/)
CC*****
CC  MYER COMPUTES THE DIFFERENCE BETWEEN THE YEAR AND A BASE YEAR. IN
CC  THIS CASE THE BASE YEAR IS 1970
CC*****
  MYEAR=YR-70
CC*****
CC  COUNT THE NUMBER OF TIMES WHICH THE OZONE READING IS
CC  WITHIN 1.5,1.0, AND 0.5 OF THE DAILY PEAK
CC*****
  DO 100 I=1,24
  IF(MXOZDA.LT. OZONE(I)+1.5)FRP015(SITE,I)=FRP015(SITE,I)+1
  IF(MXOZDA.LT. OZONE(I)+1.0)FRP010(SITE,I)=FRP010(SITE,I)+1
  IF(MXOZDA.LT. OZONE(I)+0.5) FRP05(SITE,I)= FRP05(SITE,I)+1
  SUMOZO(SITE,I)=SUMOZO(SITE,I)+OZONE(I)
100 CONTINUE
CC*****
CC  COUNT THE NUMBER OF DAYS THAT OBSERVATIONS WERE TAKEN AT EACH SITE
CC*****
  NUMDAS(SITE)=NUMDAS(SITE)+1
CC*****
CC  COUNT THE NUMBER OF TIMES AT EACH SITE THAT THE PEAK OCCURS AT PKHR
CC*****
  FRPO(SITE,PKHR ) =FRPO(SITE,PKHR )+1
CC*****
CC  TEST FOR THE MAXIMUM OZONE READING AT EACH SITE
CC*****

```

```

IF (MAXOZ (SITE) .LT. MXOZDA) MAXOZ (SITE) =MXOZDA
SMXOZ (SITE) =SMXOZ (SITE) +MXOZDA
CC*****
CC SUM OVER ALL DAYS AND ALL HOURS THE CUMULATIVE OZONE DURING *****CC
CC PHOTOSYNTHESIS, RESPIRATION, AND TOTAL *****CC
CC*****
DO 656 I =BGNPHO, ENDPHO
PCUMOZ (NUMDAS (SITE), SITE, I) =PCUMOZ (NUMDAS (SITE), SITE, I-1) +OZONE (I)
TCUMOZ (NUMDAS (SITE), SITE, I) =TCUMOZ (NUMDAS (SITE), SITE, I-1) +OZONE (I)
656 CONTINUE
EPHOPI =ENDPHO+1
DO 655 I =EPHOPI, 24
TCUMOZ (NUMDAS (SITE), SITE, I) =TCUMOZ (NUMDAS (SITE), SITE, I-1) +OZONE (I)
RCUMOZ (NUMDAS (SITE), SITE, I) =RCUMOZ (NUMDAS (SITE), SITE, I-1) +OZONE (I)
655 CONTINUE
TCUMOZ (NUMDAS (SITE), SITE, 1) =TXCUMOZ (NUMDAS (SITE), SITE, 24) +OZONE (1)
RCUMOZ (NUMDAS (SITE), SITE, 1) =RCUMOZ (NUMDAS (SITE), SITE, 24) +OZONE (1)
BPHOM1 =BGNPHO-1
DO 566 I =2, BPHOM1
RCUMOZ (NUMDAS (SITE), SITE, I) =RCUMOZ (NUMDAS (SITE), SITE, I-1) +OZONE (I)
TCUMOZ (NUMDAS (SITE), SITE, I) =TCUMOZ (NUMDAS (SITE), SITE, I-1) +OZONE (I)
566 CONTINUE
MXOZDA =0
GO TO 125
225 CONTINUE
CALL TBLE1B
CALL TITLE
CALL TABLE2
CC*****
CC COUNT THE NUMBER OF TIMES DURING THE ENTIRE DAY THAT THE OZONE IS *****CC
CC WITHIN 1.5, 1.0, 0.5 OF THE DAILY PEAK *****CC
CC*****
DO 318 SITE =1, 3
DO 356 IFR =1, 24
NMDA15 (SITE) =NMDA15 (SITE) +FRPO15 (SITE, IFR)
NMDA10 (SITE) =NMDA10 (SITE) +FRPO10 (SITE, IFR)

```

NMDA5 (SITE)=NMDA5 (SITE)+FRP05 (SITE,IFR)

356 CONTINUE

318 CONTINUE

DO 330 J=1,24

DO 220 I=1,3

PCP0(I,J)=(100.*FRP0(I,J)/NUMDAS(I)

PCP05(I,J)=(100.*FRP05(I,J)/NMDA5(I)

PCP010(I,J)=(100.*FRP010(I,J)/NMDA10(I)

PCP015(I,J)=(100.*FRP015(I,J)/NMDA15(I)

220 CONTINUE

CC*****CC

CC WRITE THE VALUES FOR TABLE TWO

CC*****CC

WRITE(6,333)HOUR(J),AMPM(J),FRP0(II,J),II=1,3),

2(PCP0(II,J),II=1,3),(PCP05(II,J),II=1,3),

3(PCP010(II,J),II=1,3),(PCP015(II,J),II=1,3)

333 FORMAT(1X,12,1X,A2,1X,'**',I4,'*',I4,'*',I4,'*',4('*,

2F4.1,'*',F4.1,'*',F4.1,'**'),'

330 CONTINUE

CALL TITLE

CALL TABLES

DO 614 J=1,3

MODP0(J)=SMXXOZ(J)/NUMDAS(J)

614 CONTINUE

DO 438 I=1,24

DO 500 J=1,3

MNPKHR(J,I)=SUMOZ(J,I)/NUMDAS(J)

MDPPAD(J,I)=(MNPKHR(J,I)/MAXOZ(J))*100.

MDPMDP(J,I)=(MNPKHR(J,I)/MODP0(J))*100.

500 CONTINUE

CC*****CC

CC WRITE THE VALUES FOR TABLE THREE

CC*****CC

WRITE(6,555)I,AMPM(I),(MDPPAD(K,I),K=1,3),(MDPMDP(K,I),K=1,3)

555 FORMAT(37X,12,1X,A2,1X,'**',2('*,F4.1,'*',F4.1,'*

3',F4.1,'*'),'

```
CALL TBLE45
IF (CUMDAS.EQ.0) CUMDAS= MAXO(NUMDAS(1),NUMDAS(2),NUMDAS(3))
DO 758 ISITE=1,3
DO 757 IDAY=1,CUMDAS
DO 756 I=1,24
```

```
RC00AD(ISITE,I)=RC00AD(ISITE,I)+RCUM0Z(IDAY,ISITE,I)
PC00AD(ISITE,I)=PC00AD(ISITE,I)+PCUM0Z(IDAY,ISITE,I)
TC00AD(ISITE,I)=TC00AD(ISITE,I)+TCUM0Z(IDAY,ISITE,I)
```

756 CONTINUE

IF (IDAY.NE.1) GO TO 770

```
TCCOAH(ISITE,1)=TCCOAH(ISITE,BPHOM1)
RCCOAH(ISITE,1)=RCCOAH(ISITE,BPHOM1)
PCCOAH(ISITE,1)=PCCOAH(ISITE,FNDPHO)
```

GO TO 880

TCOOAH(ISITE, IDAY)=TCOOAH(ISITE, IDAY-1)+TCUMZOZ(IDAY, ISITE, BPHOM1)
RCOOAH(ISITE, IDAY)=RCOOAH(ISITE, IDAY-1)+RCUMZOZ(IDAY, ISITE, BPHOM1)
PCOOAH(ISITE, IDAY)=PCOOAH(ISITE, IDAY-1)+PCUMZOZ(IDAY, ISITE, ENDPHO)

880 CONTINUE

757 CONTINUE

758 CONT INUDE

CC*****
CC WRITE THE VALUES FOR TABLE FOUR
CC*****
CC*****

DO 323 I=1.24

```
WRITE(6,324) I,AMPM(I), (RCOAD(J,I),J=1,3), (PCOAD(J,I), J=1,3)
1, (TCOAD(J,I),J=1,3)
```

324 FORMAT (26X,I2,I,X,A2,I,X,'*',3('*,F6.0,'*',F6.0,'*',
2),'*'))

323 CONTINUE
CALL TITLE
CALL TABLES


```

INTEGER*2 DA1,DA2,YR1,YR2
COMMON ATRFM,M01,M02,DA1,DA2,YR1,YR2
WRITE (6,662)
662 FORMAT (1H1)
WRITE (6,100)
100 FORMAT (35X,57('*')/35X,'*',T92,'*',/35X,'*',T92,'*'/
235X,'* VIRGINIA OZONE ANALYSIS SYSTEM',T92,'*'/
335X,'* DEPARTMENT OF PLANT PATHOLOGY AND PHYSIOLOGY, AND',
4T92,'*'/
535X,'* DIVISION OF FORESTRY AND WILDLIFE RESOURCES',T92,'*'/
635X,'* VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY',
7T92,'*'/
835X,'* BLACKSBURG, VIRGINIA 24061',T92,'*',/35X,'*',T92,'*'/
935X,'*',T92,'*',/35X,57('*')///)
RETURN
CC*****
CC WRITE THE TABLE ONE HEADINGS
CC*****
ENTRY TABLE1
WRITE(6,200)
200 FORMAT(// 'RAW DATA: AN INPUT-OUTPUT LIST TO ALLOW INSPECTIONS FOR
1 ERRORS' / 9X, 'AND CORRECTIONS TO BE MADE.' //)
RETURN
ENTRY TBLE1B
WRITE(6,300)
300 FORMAT(// 'IN SEQUENCE, THE ABOVE COLUMNS ARE: '/15X, 'CARD 1: CARD
NUMBER, SITE, MONTH, DAY, YEAR, OZONE FOR HOURS 1-12' /
215X, 'CARD2: CARD NUMBER, OZONE FOR HOURS 13-24')
RETURN
CC*****
CC WRITE THE TABLE TWO HEADINGS
CC*****
ENTRY TABLE2
WRITE (6,400) ATRFM,M01,DA1,YR1,M02,DA2,YR2
400 FORMAT (' TRANSFORMATION: ',5A4/' DURATION OF ANALYSIS: ',3(12,2X),
15H TO ,3(12,2X)//7X,'**FREQUENCY OF OZONE*',4('PER CENT OF TOTAL

```

```

2 DAYS *'), '*' /
37X, '**PEAKS AT LOCATION:**IN WHICH PEAK OCCURRED **WITHIN 0.5 OF T
4HE PEAK **WITHIN 1.0 OF THE PEAK **WITHIN 1.5 OF THE PEAK ** /
5' HOURS ** 1 * 2 * 3 *', 4(* 1 * 2 * 3 *').
6 *' / 128(*')

```

RETURN

```

CC*****
CC WRITE THE TABLE THREE HEADINGS
CC*****
CC*****
CC*****

```

ENTRY TABLE3

WRITE(6,500)

```

500 FORMAT(43X, '*' , 2(*' MEAN OF DAYS *'), '*' / 43X, '*' , 2(*' AS
2 PERCENT OF *'), '*' / 38X, 'HOURS** PEAK ON ANY DAY **',
3MEAN OF DAILY PEAKS **' / 43X, '*' , 2(*' 1 * 2 * 3 *'),
4 '*' / 38X, 51(*'))

```

RETURN

```

CC*****
CC WRITE THE TABLE FOUR HEADINGS
CC*****
CC WRITE THE TABLE FIVE HEADINGS
CC*****
CC*****
CC*****

```

ENTRY TABLE45

WRITE (6,600)

```

600 FORMAT(20X, 34X, 'CUMULATIVE OZONE DURING: ' / 26X, 'HOURS **', 4X,
2 'RESPIRATION', 5X, '**', 3X, 'PHOTOSYNTHESIS', 3X, '**', 8X,
3 'TOTAL', 7X, '**' / 27X, 75(*') /
432X, '*' , 3(*' 1 * 2 * 3 *'), '*' / 27X, 75(*'))

```

RETURN

ENTRY TBLE6

```

CC*****
CC WRITE THE TABLE 6 HEADINGS
CC*****
CC*****
CC*****

```

WRITE(6,317)

```

317 FORMAT(48X, 31(*' $'), / 48X, '$$', 25X, '$$$', / 48X, '$$$', ' OZONE LEVE
ILS REPORTED ', '$$', / 48X, '$$', 25X, '$$', / 48X, 31(*' $'), / 48X,
2 / 40X, '**', 'LEVELS', '*', (1=0-.99 2=1.0-1.99 3=2.0-2.99 ETC.)' /
3, 40X, 51(*' $'), / 40X, 9(*' $'), NUMBER OF HOURS **, ** PERCENT OF H

```

```
4OURS *',/,40X,51('*'),/,40X,7('*'),2('* 1 * 2 * 3 *')
```

```
5,/,40X,51('*'))
```

```
RETURN
```

```
END
```

```
//DATA
```